AD 754 178

Technological Forecasts

1975-2000 a descriptive outlook and method for quantitative prediction

Department of Transportation

MAY 1970

Distributed By:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE

TECHNOLOGICAL FORECAST: 1975-2000

--A DESCRIPTIVE OUTLOOK AND METHOD FOR QUANTITATIVE PREDICTION

May 1970

Release to the Public January 1973

DEPARTMENT OF TRANSPORTATION

Assistant Secretary for Policy and International Affairs

Office of Systems Analysis and Information

Washington, D.C. 20590

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No. AD 754 178
4. Title and Subtitle: Technological Forecast: 1975-2000 --A Descriptive Outlook and Method for Quantitative Prediction		5. Report Date: May 1970 6. Performing Organization Code
7. Author(s): E. I. Golding, Ph.D.; W. D. Velona; B. Poole		8. Performing Organization Report No.
9. Performing Organization Name and Address: Office of Systems Requirements, Plans and Information Office of Assistant Secretary for Policy and International Affairs, Washington, D. C.		10. Work Unit No 11. Contract or Grant No.
12. Sponsoring Agency Name and Address: U.S. Department of Transportation Washington, D. C.		13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplementary Notes The Office of Systems Analysis and Information wishes to acknowledge the study review performed for the FAA by Mr. L.S. Joel, of the National Bureau of Standards (NBS). The NBS effort was funded under Interagency Agreement No.FA172WAI-182 by the Office of Aviation Policy and Plans, Federal Aviation Administration.

16. Abstract

This report is divided into two parts. The first part provides a description of expected trends in transportation for both passenger and freight movements for the next 30 years. The second part describes a methodology for forecasting, at an aggregate level of detail and as a function of time value, out of pocket costs and trip distance, the modal split of passengers in a forecast year between 1975-2000. The second part also describes the use of the methodology to examine the probable effects of emphasizing the development of one technology over another. There are also 4 Appendices. Appendix 1 describes a 1965 Passenger Mile Data Base Table, as a function of mode and trip distance. Appendix 2 similarly describes a 1965 Commodity Ton-Mile Data Base Table. Appendix 3 describes the results of a Delphi Forecasting Exercise and Appendix 4 describes the parameters used to define each system used in the modal split.

17. Key Words	18. Distribution Statement
Future Transportation Systems Aggregate Modal Split Technological Forecasting 1965 Passenger Mile & Commodity Ton-Mile Data Base	This is the authors' report of their analytical effort. Its contents do not reflect the official views or policy of the Department of Transportation.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
None	None		

Form DOT F 1700.7 (8-69)

EXECUTIVE SUMMARY

* The report "Technological Forecast 1975-2000 -- A Descriptive Outlook and Method for Quantitative Predictions" describes the results of the first phase of a two phase research effort intended to:

  - - Provide a comprehensive abstract of those developments and feasible concepts in transportation technology which may offer opportunities for improvements in the U.S. domestic transportation of goods and persons.

  - - Develop a methodology which will serve to identify the relative value and appropriate levels of investment in research and development for each new system based on quantitative measurements of its impact on the movement of goods and persons and some of the impacts on the surrounding environment.

* In phase I, the research effort has focused on:

  - - Identification of technological trends which offer opportunities for improvement and change over the 1975 to 2000 time period.

  - - Description of new transportation system concepts and their operating characteristics.

  - - Expected research and development costs and time requirements for new systems.

  - - Methodology for predicting the modal choice of passengers over a forecast period of 25 years.

* In phase II, it is intended that the research effort will focus on:

  - - A methodology for predicting the modal split for the movement of goods over the next 25 years.

  - - Development of methodolgcies for the measurement of the impact of transportation on such factors as safety, pollution and noise.

  - - Identification of capital investments required to provide a particular new system of transportation.

  - - An investment analysis which will measure the relative merit of new systems and the level of R & D funding consistent with these findings.

* The most significant accomplishment of this research effort has been the development of a modal split tool which relies on U. S. wide totals and averages for its input data. Use of aggregate data is significant in that the results of such analysis are immediately useful for determining estimates of national requirements. The use of this tool produced the charts on pages 116 to 145. For example on page 116 it will be noted that in 1965, in dense urban areas, for single passenger trips up to 2.5 miles, the distribution of passenger-miles traveled was 89.2% by auto, 4.4% by bus, 4.3% by train, and 2.1% by taxi. A new system, the MAC-1, 1/ is introduced in 1980. The presence of the new system results in a redistribution of passenger-miles. The MAC-1 is estimated to receive 65%, the auto 30%, and the bus, train and taxi, 5%. Separate analyses are provided for various combinations of distances, type of locale and group size. Pages 83 to 115 describes the manner in which these results are obtained. Briefly, the procedure is developed as follows:

- - A basic set of input data as described in Appendix 1 was established and includes: the 1965 distribution of passenger-miles by distances traveled, by mode and by size of group; a forecast of income distribution for any year; and a forecast of the increase in total passenger-miles for any year.

- - A basic set of data as described in Appendix 4 was defined for travel velocity and out-of-pocket costs applicable to each mode for each set of distance blocks, locales and group sizes. This data takes into consideration each segment of the trip including access modes and access time at both the origin and destination.

- - The value of a trip is measured by its out-of-pocket dollar cost plus the value of time in travel. By assigning different values to time, it is possible to identify the least costly mode at any distance and any value of time. The 1965 passenger-miles for each mode are assigned to each of these zones. The assumption is also made that at the lower value of time values, the choice of mode is more a function of out-of-pocket costs than travel time. However, at the higher spectrum of time values, the choice of mode is more a function of travel time. The methodology used biases the modal split to reflect this assumption.

- - A correlation is established between the 1965 income distribution and the value of time distribution for each set of passenger-miles. The assumption is made that the number of passenger-miles applicable to a given value of time is related to income distribution. The results of this correlation may then be used to measure shifts in passenger-mile distribution to any mode in any year if the input data described in Appendices 1 and 4 are provided.

- - To properly phase the analysis, the date when new systems could be available for service must be estimated. For this purpose, the Delphi technique described on pages 63-75 & Appendix 3 was used. Individuals

---

1/ See page 4 of this summary for a brief description of MAC-1 and other technologies.

with expert knowledge of what is required to develop a new technology were requested to prepare judgement estimates of R & D costs and probabilities of reaching specified performance levels by a given date. Reiterating this process through two cycles permitted a determination of the probability of accomplishment on any date. Arbitrarily, the decision was made to select that date on which the probability of completing R & D was estimated to be 0.7.

* Concepts and developments in new passenger systems are the result of a number of technological innovations and decisions whose engineering feasibility is proven or of such high probability as to give reasonable assurance of the success of further research. These developments together with descriptions of specific modes are contained in the first 55 pages of the report and are summarized below:

  - - The characteristics of air modes for both passengers and cargo will be influenced by the development of high capacity jet aircraft and the supersonic transport for longer hauls, and the use of high capacity vertical takeoff aircraft for shorter hauls. Various configurations of these systems are in use or in advanced stages of development.

  - - New concepts for surface passenger modes are characterized by:

    . . Heavy reliance on electronics to maximize automated movement and control of vehicles;

    . . Extensive use of electrical power units including linear motors, batteries and fuel cells;

    . . Improved vehicular suspension based on projected use of more carefully constructed guideways and tracks, the use of air suspension, and possibly magnetic suspension;

    . . Greater reliance on a range of vehicle sizes and trains whose capacities more closely reflect the number of travelers and the point in time when travel is demanded;

    . . Reliance on a variety of systems, each suited to serve specific volumes of travel, trip lengths and directional diversity.

    . . Use of multi-modal combinations which tend to reduce travel time at little or no sacrifice in comfort or convenience.

- - The outlook for surface cargo modes is less clearly defined. Present trends indicate increased expansion of containerization and piggyback techniques, a general trend to increased vehicle size and continued expansion of computerized techniques for control and expenditing of shipments. Experiments are being made in the use of surface effect vehicles and pipeline movement of cargo.

* The systems described in the report are those which have been defined by the Office of the Assistant Secretary for Systems Development and Technology, the Urban Mass Transportation Administration, the Federal Rail Administration, and the Federal Aviation Administration. Some of the less familiar passenger systems described in the report are:

- - MAC-1; a low speed high capacity conveyor type system for use in such Major Activity Centers as central business districts and terminals.

- - MAC-2; a low speed, medium capacity, personal-vehicle-on-guideway system for use in central business districts and terminals.

- - Dial-A-Bus; a computer-scheduled jitney-size vehicle designed to provide door-to-door service in low density areas characterized by diffused origin-destination trips.

- - PAS; a Personalized Automobile Service which uses small battery operated autos at depots 500 to 1000 feet apart in low density areas for local travel.

- - NET 1-2; an urban wide Network of guideways 1 or 2 miles apart for fully automated continuous auto type vehicle flow at 50 to 70 miles per hour.

- - NET 3; a second generation NET development to permit street to guideway access to vehicles.

- - FLT-1; a Fast Transit Link designed to provide high velocity (100 to 140 MPH), high capacity travel between major centers for trips up to 50 miles.

- - FTL-2; service similar to FTL-1 with velocities of up to 300 MPH based on use of evacuated tunnels to reduce drag.

- - HSR-A; intercity rail systems based on improvements to vehicles and existing track which will allow maximum speeds of 150 MPH.

- - HSR-C; completely new rail system designed to provide maximum speeds of 200 MPH.

- - TACV; a guideway and air cushion vehicle system for intercity travel at maximum speeds of 300 MPH.

- - TVS; vehicles traveling on continuous tracks in reduced pressure tunnels at intercity speeds of up to 400 miles per hour.

- - Auto-Pallet; fully automated individual flow pallets which bodily transport automobiles for intercity travel at speeds of up to 130 miles per hour.

* A detailed description of U. S. domestic passenger and cargo movements is contained in Tables 1-1 and 1-1a in Appendix 1 and Table 2-1 (page 2-10) in Appendix 2. The highly competitive characteristics of the automobile are clearly revealed in these findings.

CONTENTS

1.0 Technological Forecast Objective

The objective of this report is twofold. First, it is intended to provide a qualitative description of the possible technological innovations and trends that may arise in the systems that can be used to transport passengers or goods from 1975 to 2000. Secondly, it is intended to provide a quantitative methodology that examines, in an aggregate sense, aspects of the impact of such technological change on modal choice. Consequently, the report focuses on the following:

- Trends for improvement and change;
- Description of the more probable new systems;
- Transportation markets that could be served by new systems;
- Expected R&D costs for new systems; and
- Methodology for predicting modal choice for passengers for the next 25 years.

2.0 Descriptive Summary of Technological Trends

A cursory survey of viable technology that appears either on the drawing board, in initial prototypes, or in final stages of experimental test and design indicates that technological changes and improvements in transportation will be evolutionary and gradual.

The principal deterrents to revolutionary change is cost and public acceptance. For one thing, there is the cost to overcome engineering and material problems, the cost to acquire land or air rights, and the cost

to procure sufficient equipment and maintain it in satisfactory operating condition to encourage public use. For another, there is the fear of the lack of the public acceptance of new systems. This acceptance depends many societal variables. Demonstrations have to come first to acquire a reasonable indication that the public will in fact use what is provided. Nevertheless, change will occur. The trends may be as follows:*

2.1 Air Mode

Air carriers appear to be the fastest growing mode of transportation in the U.S. for both passenger and freight traffic. They have doubled their domestic passenger-miles in only 4 years and now are the predominant common carriers by far in terms of intercity passenger-miles. While domestic air freight traffic has likewise doubled in this 4-year period, air carriers still handle only 0.1 percent of total intercity freight ton-miles, although this accounts for 1.5 percent of total outlays for such service.

International passenger and freight services of U.S. air carriers appear to be growing at even a faster rate, and these carriers now handle 87 percent of the total number of U.S. travelers to overseas points.

*Description of specific systems that seem most probable for future implementation are discussed beginning with paragraph 2.

The giant subsonic jet transports soon ready for the market can be expected to maintain this upward trend. The supersonic transports expected to arrive in the early 1970's should stimulate long-distance travel, while improved short-takeoff-and-landing (STOL) and vertical-lift (VTOL) aircraft, with improved and larger carrying capacities, available in some versions by the late 70's and early 80's, may enable the airlines to capture a sizeable share of the high volume, short haul intercity market. A major deterent to using new aircraft more effectively could be the current lag in expansion and modernization of airways and airports, including terminal facilities.

2.1.1 Long Haul Air Mode Market

The U.S. is tending to move into the big "Jet Aircraft" age. Large 250-350 passenger tri-jets should be in service by late 1971 or early 1972 with the introduction of the Lockheed L-1011 and the Douglas DC-10. These aircraft, designed for the medium range travel market, can become subject to "stretch" modifications as the current family of jets have received and thus be adjusted to carry more passengers and serve a longer range market.

In addition, introduction of the Boeing 747 and the Lockheed C5A, in 1970, will be able to handle an average of 400 passengers and as many as 900 for the passenger version of these aircraft

respectively. Cargo versions of these aircraft may provide the breakthrough that air carriers require to make air freighters competitive in the cargo market. For instance, the B-747 may be able to handle upwards of 267 tons and the C5A about 140 tons.

By 1980 these initial giant jets could form the backbone of air bus service between major cities of the U.S. and overseas. The transport containerization trend now underway could help augment the entry of giant all cargo transports that can work with and interchange cargoes with surface carriers.

The next step, as a result of the Federal Government concurrence, is the development of SST's. Flying non-stop, carrying 300 passengers at least a distance of 4,000 miles, at around MACH 3, these aircraft will link major coastal cities of the U.S. with most capitals of Europe and Asia. They are expected on the market, given no engineering or unforeseen program setbacks, by 1980. The number of SST's that might be demanded depends on whether or not sonic boom problems, which restrict flight profiles, can be solved. Following on the heels of the SST for long range aircraft, the hypersonic transport is expected. This type of aircraft could fly in excess of 4,000 mph and operate probably at altitudes of 100,000 feet or more. It might come

into the market by 2000. While considerable research is being done on the hypersonic concept by NASA, the Air Force, and major aircraft manufacturers, developmental costs could be many times that of the SST.

2.1.2 Short Haul Air Mode Market

Engineering breakthroughs in vertical lift type aircraft making such aircraft economically competitive with other transport modes should occur. Air carriers would then have good reason to enter into the 50-150 mile passenger transportation market.

Short haul market aircraft are usually considered in 3 classes. Helicopters (VTOL), short take-off and landing (STOL) and convertiplanes, which combine the best attributes of the strictly VTOL and STOL aircraft.

Studies indicate, however, that not before 1980 can large, 80-100 passengers, 150-300 mph vehicles be expected to enter the market. Demonstrations using small helicopters or STOL aircraft to haul passengers on small trips (less than 50 miles) has not proven economical. People have not accepted the service to the extent to make it a self-sustaining operation. Larger and faster aircraft with the ability to land on small airport pads in central business districts or on nearby suburban pads and capable of linking these points to corresponding sites in

other cities may be required to make the short haul market operations profitable. A number of technical breakthroughs, however, are required before real success can be achieved. They are primarily during the terminal phase of flight as follows:

- Reduction of fuel consumption;
- Reduction of noise profiles to acceptable levels; and
- Control of vehicles during non-aerodynamic lift conditions

Overcoming these technical problems would eventually produce a vehicle that had both the best performance attributes of a helicopter and a conventional aircraft (CTOL). Advanced engineering concepts are considering many aircraft variations to accomplish this flight profile. The most advanced types are convertiplanes, which can take off and land vertically, then rotate engines for normal horizontal flight achieving speeds in the 400-500 mph range. Some use large fan-type props which at present produce less noise than jets. Other types use rotor blades for vertical lift and prop engines for horizontal flight, one version stowing the rotors during normal flight.

2.2 Surface Modes

2.2.1 Technological Trend For Autos

The expected trend is towards "personalized vehicles" with computer sensing and correcting devices to control the vehicle during a cruise phase of a trip. Such autos will probably be adaptable to function either on guideways or on conventional roadways. They will be designed to use self-contained engines or electrical energy from the guideways as a source of power for propulsion. This trend will follow from an evolutionary process now in effect. For instance, communication systems capable of providing the driver with traffic control information to enhance the safety of his trip, such as road conditions ahead, passing hazards, etc., are being tested and evaluated.

The major emphasis in the future may well be toward producing low pollutant propulsion sources, especially for travel within city cores and densely populated areas. The most effective breakthrough for the future could be in achieving efficient electric propulsion systems for use in vehicles with the same structural safety and riding comfort as we have today but with less gross weight and less noise generating characteristics. The most effective breakthrough for the near term may be in proving out the economical and practical use of a fuel (i.e.,

compressed natural gas) that significantly reduces pollutant emissions from internal combustion engines.*

Initially, electrically propulsed cars will carry probably no more than 2 adults and 2 children for specific trips at velocities of less than 40 mph. The chances are that economical methods for recharging batteries while the vehicles are in motion will be achieved. As a consequence, the duration, frequency, and velocity permitted during such electrically propelled trips will be increased. On the other hand, the chances for developing a longer life battery to provide energy for such increased performance capabilities without frequent stopping for recharging may be remote without a new breakthrough in electro-chemical-material technology. At the same time, new innovations can be expected in the operation of internal combustion engines and turbines. Better anti-pollutant devices are anticipated which will make these engines more acceptable to the public than they are today.

---

*Los Angeles Pacific Lighting Company has had for a few years a variety of vehicles under test using natural gas as an internal combustion engine fuel. Measurement of pollutant emissions have shown .5 gram/mile for nitrous oxide and 2 grams/mile for carbon monoxide. This is a significant reduction from 4 grams/mile and 28 grams/mile measured respectively from conventional gasoline burning engines. More extensive tests are underway by government and industry to evaluate further this concept. Time - October 17, 1969.

The technological possibility also exists for a class of hybrid vehicles with respect to engine propulsion and operation. Such vehicles might combine the best of internal combustion engines, suitable for long-high velocity sustained travel, with electric engines, suitable for short-low velocity intermittent travel.

Because of antipollutant requirements, steam driven autos may, at times, seem a contender for marketing. The large spatial requirement to house a closed cycle system, coupled with the possibility of more complex maintenance requirements (i.e., repair for 4 wheel electric drives, regenerators, etc.) and complete industrial retooling, however, could hinder public and industrial acceptability as well as any extensive mass marketing.

2.2.1.1 Automated Highways

The suburban sprawl, which feeds low density patterns of residential development and the high dispersion of employment centers within a region, produces a multi-origin/multi-destination transportation demand which seems best served by "personalized" vehicles discussed earlier. Personal vehicles, however, controlled by a driver alone do not produce efficient high volume transportation in corridors (on expressways) where

many trips coincide and high volume is required. The concept that appears very feasible as an initial evolutionary step to achieve high volume on highways is one in which production cars could be modified to accommodate mechanisms that would receive electronic signals to control their longitudinal and transverse positions on a highway. Vehicles would traverse automated highways, only when they have been modified to operate with electronic guidance packages in control. Vehicles without electronic packages would have to operate in a manual mode on a lane of conventional roadway parallel to the automated highway.

Even though it has been estimated that an automated highway could have 8 times the capacity of a conventional lane, it is doubtful that it will be placed into operation quickly. It will have to evolve. For instance, the Bureau of Public Roads has had underway a class of "automated" assists to the driver. These are primarily electronic means of communicating to the driver traffic conditions along the highway or means of metering vehicles into traffic lanes. Additional research is needed to gather data on safe merging, queuing, egress and access problems common to high

volume traffic conditions. These items of operational safety are very fundamental to the whole area of automated traffic. They will have to prove out before other more complex and more automated modes of traffic for interurban or intraurban travel can be implemented.

2.2.2 Technological Trends for Public Transit

There are several systems that seem possible for future development and implementation. They are discussed here as functional, generic systems applicable to specific trip distances. Later on in the report, under the Delphi Exercise explanation, their probable operational dates are estimated.

2.2.2.1 Major Activity Systems (MAC)

This consists of service for short trips (0-2.5 miles) within small densely populated major activity centers such as central business districts, air terminals, shopping centers, and universities.

Two possible types:

MAC 1*: Fast pedestrian conveyors (belt driven)

MAC 2 : Light weight 3-passenger automated vehicles (on guideways)

---

*Some relatively short conveyor belt systems are in use at some transportation terminals today. These are the initial prototypes of MAC-1 Systems. Also, grants for feasibility studies of entirely new rapid transit systems based on existing vehicle technology have been made to Seattle, Atlanta, Los Angeles, San Juan, Pittsburgh, and Baltimore. Pittsburgh, for example, is undertaking demonstration of the Skybus system, a 20-passenger vehicle using rubber tired wheels on guideways designed to permit velocities of 40 miles per hour between stations.

They could be designed to move people between office buildings, around shopping promenades and through transportation centers such as air terminals. MAC routes and stations would be spaced at intervals of 500' to 1,000' with 1 to 3 minutes walk of travelers' origin or destination.

Stations and guideways of both systems could be elevated structures, enclosed and air conditioned or underground.

2.2.2.2 Public Automobile Service (PAS)

This consists of a personal rapid transit type service (0-2.5 miles) that would be used by accredited drivers and co-travelers for local area trips. Travel would be restricted to city streets, in rented vehicles similar in size to today's compact car, propelled by electric engines with a top speed of 25 mph. Trip duration would be 2 to 10 minutes and the vehicle would be 80" long, 54" wide and 60" high; weighing 1,000 lbs. empty and carrying a pay load of 350-500 lbs.

2.2.2.3 Dial-A-Bus

This is a computer-scheduled, flexible public carrier system that would pick up passengers at their doors or at a nearby bus stop shortly after a passenger had

telephoned for service. The system's operational concept falls between that of a bus and a taxi which makes use of a jitney-sized vehicle routed and dispatched by a computer and a local "command and control" communication link. It could serve a diffused pattern of trip origins and destinations in predominately low density suburbs. Although its success would be subject to many variables, the greatest being demand density, it is believed that it would be most efficient at 100 trips per hour per square mile, a level that is hardly practical for conventional bus service.

2.2.2.4 NET Systems

NET* is the generic term used to describe a class of city-oriented "circulation and distribution" type systems that consist of sets of guideways with their own set of automatically controlled vehicles. Carrying approximately 4 passengers, the trips are designed for 2.5-20 mile range.

There are three system possibilities which are alternative ways to provide extended - area service. They

*NET: A symbol for Area Wide Network Transportation System around a city core the NET System's span is reduced and it has been identified as either a "People Mover or Personal Rapid Transit". Likewise between cities certain loops have been stretched and the system called either an FTL (Fast Transit Link) or an LH (Line Haul) System.

represent a progression in technical achievement with the more technically advanced systems incurring less transfers. The vehicles would ride on rubber tires and be driven by electric motors. A speed of 70 mph would be possible with line capacities as ranging from 500 to 1,000 to 10,000 passenger/hr. The latter figure depending on complexity of controls that can be justified and economically implemented.

NET-1:

The NET-1 system would consist of sets of independent loops of guideways, each with its own set of captive cars. Each loop would provide for two-way traffic. Each might be several miles long, with or without intermediate stations but it would contain no branching or switching other than to the stations that are located off-line. Where a loop interfaces with another loop, travelers could transfer to a vehicle on the second loop. A traveler could route himself over the network. Many travelers would have to transfer between lines once or twice and would use two or three different loops and different vehicles during a NET-1 trip. Since all cars

on one loop would be traveling the same route, larger cars could be used between stations that have heavier traffic. Automatic control apparatus would switch cars into off-line stations, slow them, accelerate them again, merge them back onto the line, and maintain their headways.

NET-2

The NET-2 system would have the same general mode of operation as the NET-1 except that in the NET-2 interchanges between the lines would permit allowing vehicles to be routed over the entire area-wide network to reach any station. Only 4 passenger size vehicles would be used which are captured to the network. A traveler would use a single vehicle in making his trip. His route would be established by a system control apparatus and travel, without transfer between any pair of NET-2 stations would be possible.

NET-3

The system would have all the capabilities of NET-1 and NET-2 plus a dual mode capability. The vehicle could be switched off the special guideways and driven on city streets. With this system, a single battery operated vehicle could be driven almost from door to

door without any transfers. The vehicles for NET-3 would require a considerable amount of new design work to provide the dual-mode capability, but the NET-3 system would be able to accommodate dual-mode vehicles deisgned especially for such services as the delivery of mail and parcels and the transportation of school children. Vehicles entering the NET-3 guideways would have to be checked automatically for mechanical defects before being merged into the high speed, automatically controlled part of the system.

In comparing the NET systems it is noted that the control problems of NET-1 are relatively simple, those of NET-2 are substantially more difficult, and those of NET-3 are most difficult of all.

NET guideways and stations can be elevated, at grade, below grade, or underground. The choice will be influenced mainly by the availability and costs of rights-of-way, the costs of construction, and the economic and aesthetic impacts of the routes on adjacent properties and residents. Underground routes could be the most costly but the least objectionable of the alternatives. Elevated routes located above streets, rail lines, and othor expedient alignments will be the

least costly--at least in areas that are already developed--but may be strongly opposed on aesthetic grounds.

2.2.2.5 Fast Transit Links (FTL)

Although described as a coming technology trend for trips in the 2.5 to 20 miles trip length, this system is also applicable for trip lengths from 20 to 50 miles. It would supplement the NET systems by providing a higher speed service for the longer trips. Accomplishing higher speeds with safety and economy is the principal technical advantage of FTL systems. Two FTL alternatives, FTL-1 and FTL-2, provide systems in different speed ranges. Both use special guideways and air cushions, rather than wheels, to guide and suspend the vehicles; both use linear induction motors powered by external sources for propulsion and braking.

FTL-1

The FTL-1 system, could provide block speeds of 100 to 140 mph. The guideways and stations would have to be isolated and protected, but could be elevated, at grade, below grade, or underground.

FTL-2

The FTL-2 system would employ two additional features to achieve speeds up to 300 mph. The guideway would be fully enclosed and almost completely evacuated to reduce air drag on the vehicles; and the guideway would follow a gravity profile to reduce the power requirements and to avoid the passenger discomforts that are normally associated with high acceleration and deceleration rates.* The FTL-2 vehicles must be sealed and pressurized to maintain a comfortable environment for passengers while the vehicle operates in a vacuum, and because of its gravity profile, the FTL-2 guideway must be underground between stations, the stations, however, could be located at any desired elevation. FTL-2 stations would require heavy, airtight doors to separate the platform from the evacuated guideway. Escalators and elevators would be provided where required.

FTL Vehicles

Three sizes of vehicles are possible, two for FTL-1 and one for FTL-2. A large vehicle (80 passenger) or a

---

*At the shorter ranges, less than 50 miles, the FTL-2 is similar in design to the Gravity Vacuum Tube System proposed by L. K. Edwards. At longer distances the generic term TVS is often used to describe similar systems.

small vehicle 20 passenger* are considerations for the FTL-1. The large vehicle is somewhat more economical on lines with peak-hour volumes of over 10,000 passengers. The small vehicle is more efficient at lower volumes. Only a relatively large vehicle (52 passenger) is considered for the FTL-2.

2.2.3 Technological Trends for Buses

Buses have had a large impact on urban mass transportation. A little more than 70% of the total number of persons carried on transit lines of the U.S. are handled by urban bus lines. Bus lines in many cities, however, are losing popularity because of discomfort, inconvenience, and uneconomic utility to riders. Some technological changes can be expected but they probably will be small. The focus will be on improvements for engines and the bus structure itself. The former should be similar to improvements expected for trucks and the latter to make the ride more comfortable for passengers. Assuming that other new surface transport modes come into being as forecasted (Paragraph 2.2.2) by 1990, the use of the conventional bus for trips other than intercity should be diminished. The forecast methodology used

---

*The 20-passenger FTL-1 vehicle has been estimated to be 40 feet long, 5 feet wide, and 6 1/2 feet high. Its empty weight is 7,300 pounds, and its payload is 3,000 pounds.

in this report indicates that if Public Auto Service Systems, NET Systems and Fast Transit Links come into the inventory, the need and use for the conventional bus will be significantly reduced.

Until the new systems become available, demonstrations to evaluate the use and service of modified buses and modified bussing systems can be expected. Ideas such as exclusive bus right-of-ways and dual mode capabilities (Paragraph 2.2.3.1) will be tested and evaluated in various parts of the U.S. Conventional buses could be instrumented to contain two-way radios or moderately modified to hold the "rail-road" gear in order to test out different configurations.

2.2.3.1 Dual Mode Bus

This system consists of modifying an existing technology and because of its relatively inexpensive cost* as compared to other possibilities, could be implemented rather quickly in selected locations. It consists of a passenger production bus equipped with retractable

*Estimates for costs have been made as follows:
- $12,000 to $15,000 for converting buses on production-type scale;
- $35,000/mile for new welded rail or $15,000/mile for "in place" welding of existing rail; and
- 1.0¢ to 1.2¢/seat-mile for Direct Operating Cost with 25-20% load factor.

railroad wheels for fast point-to-point transportation over uncongested rail lines. It has the advantages the flexible pick-up and distribution capabilities of a rubber-tired mass transportation vehicle as well as the speed and reliability of a unit traveling on an exclusive and uncongested right-of-way. Tests on experimental rail-bus configurations during 1968-69 proved technical feasibility, however, there were some operational problems. For instance, during a demonstration test in a 7-inch snowstorm, an experimental rail-bus lost traction on the rails and became bogged down in the snow. Also, the highest quality ribbon welded rail is necessary to achieve maximum riding comfort within the rail-bus. With continuous welded rail, speeds up to 50 mph could be obtained without passenger discomfort in conventional production buses. Larger buses with engineering modifications to prevent sway should be able to reach speeds of about 60 mph. Initial service could be for intraurban travel, alleviating the access problems to metropolitan airports.

2.2.4 Technological Trend For Trains

2.2.4.1 Passenger Trend

The future trend affecting railroads is conditioned by the evidence of current and historical statistics compiled on passenger and commodity rail movement. For instance, for passenger movements, there has been a steady drop in intercity passengers carried, passenger miles generated and in passenger revenue as evidenced by Figures A, B and C below.

FIGURE A

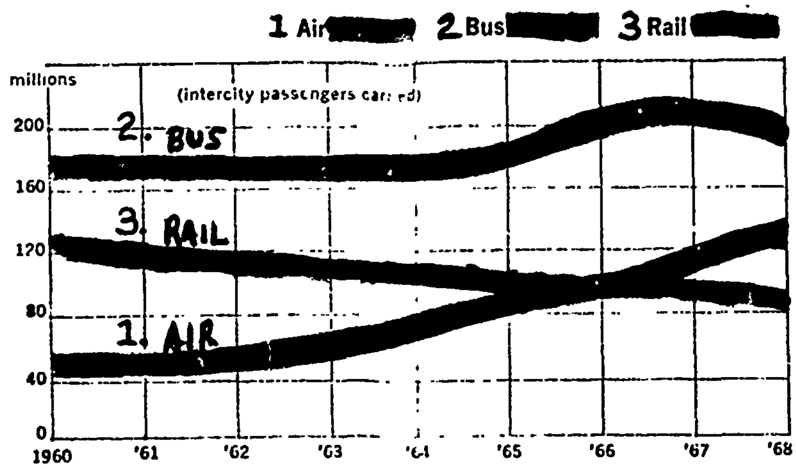
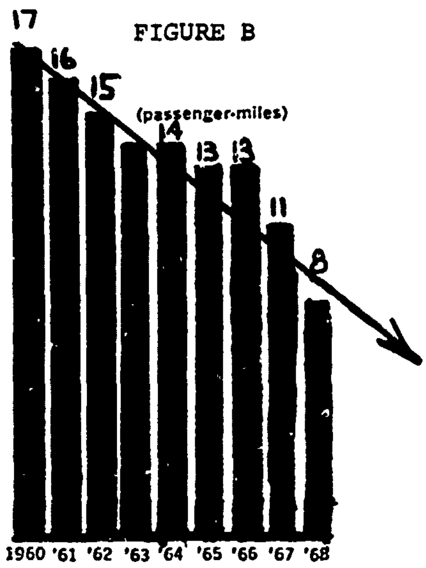
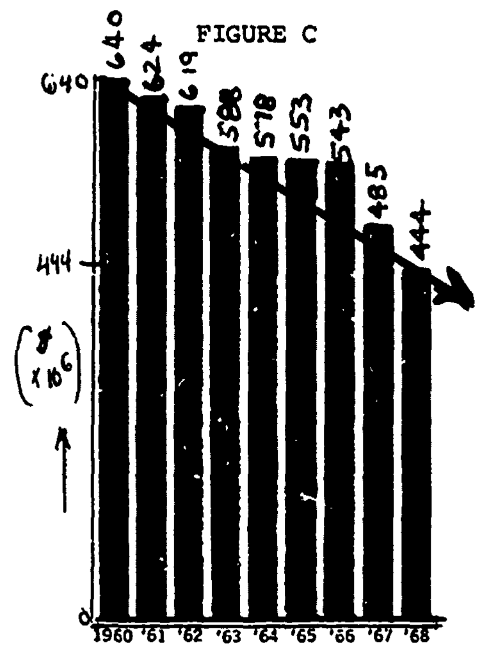


FIGURE B



Source: AAR

FIGURE C



Source: AAR

Coupled to this is the increasing concentration of the nation's population into select regions causing high density corridors with serious traffic congestion problems on both airways and highways. It would seem a reasonable approach for people to switch to the rail mode in order to avoid congestion discomforts. This has not occurred. However, to encourage movement to the rail mode and offset the declines illustrated in Figures A-C, passenger train modernization and demonstration programs, similar to that instituted in the Northeast Corridor, will probably be continued in other selected corridors of the United States.

This depends on the outcome of tests underway through the spring of 1970. If there is an impetus to continue train modernization, it will follow probably the pattern set by programs of the Budd Company and United Aircraft. These consisted of trains designed to have speeds of at least 150 mph, (averaging about 125 mph), and to have rail cars with specially designed reclining seats, carefully controlled heating and air conditioning, and special acoustical treatment to insure low noise levels. Furthermore, the United Aircraft trains (designed by United Aircraft but built by Pullman Standard) are intended as more than a modified high speed train. They are an attempt at an evolutionary fast train which makes more use of aerodynamic design principles than ever before. For one thing, the cars are all aluminum with a silhouette 2 1/2 feet lower than conventional rail passenger cars. This lower center of gravity combined with a special pendulous suspension system permits the cars to bank inwardly around curves. Consequently, the new trains are expected to operate on present road beds at speeds of up to 40 percent greater than conventional equipment.

In summary, there is some chance that passenger trains, over the near term, if modernized and if operated with competitive fare and frequency of service structures as compared to other available modes could be able to capture significant parts of selected, highly populated intercity markets. The Metroliner-Washington to New York demonstration seems to support this hypothesis. Initial reaction by the public for its acceptance and use has been high. Runs are usually sold out. It is too early, however, to predict that this initial reaction is the forerunner of a specific trend. Rail passenger-train modernization programs in the past have met with eventual failure. Non-participating railroads in the current demonstrations have not expressed significant interest for similar programs on their lines. They have had a wait and see attitude.

2.2.4.2 Freight Trend

The railroad, although still the predominant mode for the movement of intercity freight, in terms of ton-miles, is gradually losing some of its share of the market to other modes. For each successive year

between 1961 and 1966, rail freight ton-miles increased by sizeable amounts, but the average marginal revenue gain per ton-mile (average over-all unit cost of rail freight service to shippers) per year declined. Furthermore, in 1967, while rail ton-miles dropped moderately, the rail's relative share actually declined sharply. Some recovery of traffic volume is estimated for 1968, but the trend of the rail share appears to be continuing down.

The industry looks to improved technology as one means of reversing these trends in the years ahead. This may come from such improvements and innovations as automated freight car control (i.e., freight car data center system) unit-trains, high-capacity cars, and both TOFC (trailer-on-flatcar) and COFC (container-on-flatcar) service.

AUTOMATED FREIGHT CAR DATA CENTER

The nationwide rail system interchanges 1.8 million freight cars among several hundred carriers. The problem of monitoring them is an extremely difficult

one. Through the use of new computer technology and "instant" communications, the elimination of this enigma seems close at hand.

A number of railroads have developed computerized freight car data centers for use on their own lines, but the rail industry has recognized that such centers must be tied into a national system. The Association of America Railroads has approved the creation of such a system pinpointing the location of types of cars needed, supplying shippers with information on enroute shipments, establishing an "up-to-the-minute" industry inventory of every interchange freight car, and allowing automatic collection and storage of special data on rolling stock, such as maintenance and routine servicing data. After the first year of operation, such a nationwide system could mean an increase in freight car utilization of as much as 10% or the equivalent of 180,000 new freight cars. Other expected benefits will be the efficiencies generated through faster and more accurate information for use in accounting, scheduling, routing and other rail operations.

By reducing freight car interchange errors, which cost about $50,000 a day, the new system is expected to cut this to only $5,000 a day, saving approximately $16 million a year.

UNIT TRAINS

Such trains usually consist of approximately 100 freight cars, many with 100-ton capacity, that haul a single commodity and that operate in a shuttle-type, point-to-point service. This innovation will not only encourage the introduction of new rolling stock equipped with built-in, rapid loading/unloading features but also stimulate other improvements such as the use of lighter-weight and larger-capacity equipment.

To date, most u t-trains have been used to haul coal. It is estimated that nearly 90% of coal is currently being transported in this manner, at rate reductions of 25% to 40%. Savings could run as high as $100 million per year for the utility industry alone which uses coal as its major fuel. With the trend in the use of unit-trains continuing other commodities besides grain such as chemicals and even solid wastes could begin being hauled in this manner.

CONTAINERIZATION

Flowable bulk commodities are particularly well suited for unit-train operations, and the potential for moving general or packaged freight in such trains also exists. Such freight would have to be "containerized" to permit the fastest possible turnaround, which is vital to unit-train operations. Service already exists between Los Angeles and Chicago and transcontinental container unit-train service could come about if the "land-bridge" idea takes hold. Under this proposal, U.S. and Canadian railraods would link containership service between Asia and Europe, hopefully cutting the time and cost presently required using the ocean routes via the Panama Canal. The containers could be owned either by shippers or the connecting steamship lines.

Containerization has been most applicable to shipping and international freight movements. Figure D illustrates a projection of liner cargo that could be handled by containerization through the year 2000. If the railroad industry does intend to bring about the land-bridge idea, they will have to have cars and power units capable of carrying and pulling containerized loads at an economic rate.

PIGGYBACKING

The volume of traffic moving via piggyback has increased five-fold during the last 10 years and the use of this rail mode is expected to increase.

Presently in piggyback service are over 29,000 flatcars and 77,000 truck trailers and containers. The major form of piggyback has been TOFC, or "trailer-on-flatcar service", which accounts for 9/10th of the total. While drive-on/off loading and unloading is more commonly used, many variations of side and lift-on/off operations are in use or being tested. COFC, or "container-on-flatcar" service accounts for only 1/10th of total piggyback traffic, but is expected to pick up sharply if so-called "land-bridge" COFC service for containerships serving Asia and Northern Europe proves attractive. For domestic service, a big boost could result from such innovations as the Santa Fe's high-speed (averages over 50 mph) Super C TOFC/COFC trains that are now operating six days a week between Los Angeles and Chicago.

FREIGHT CAR CONSTRUCTION:

The trend in freight car construction is towards the "jumbo" size, with built-in cargo loading/unloading

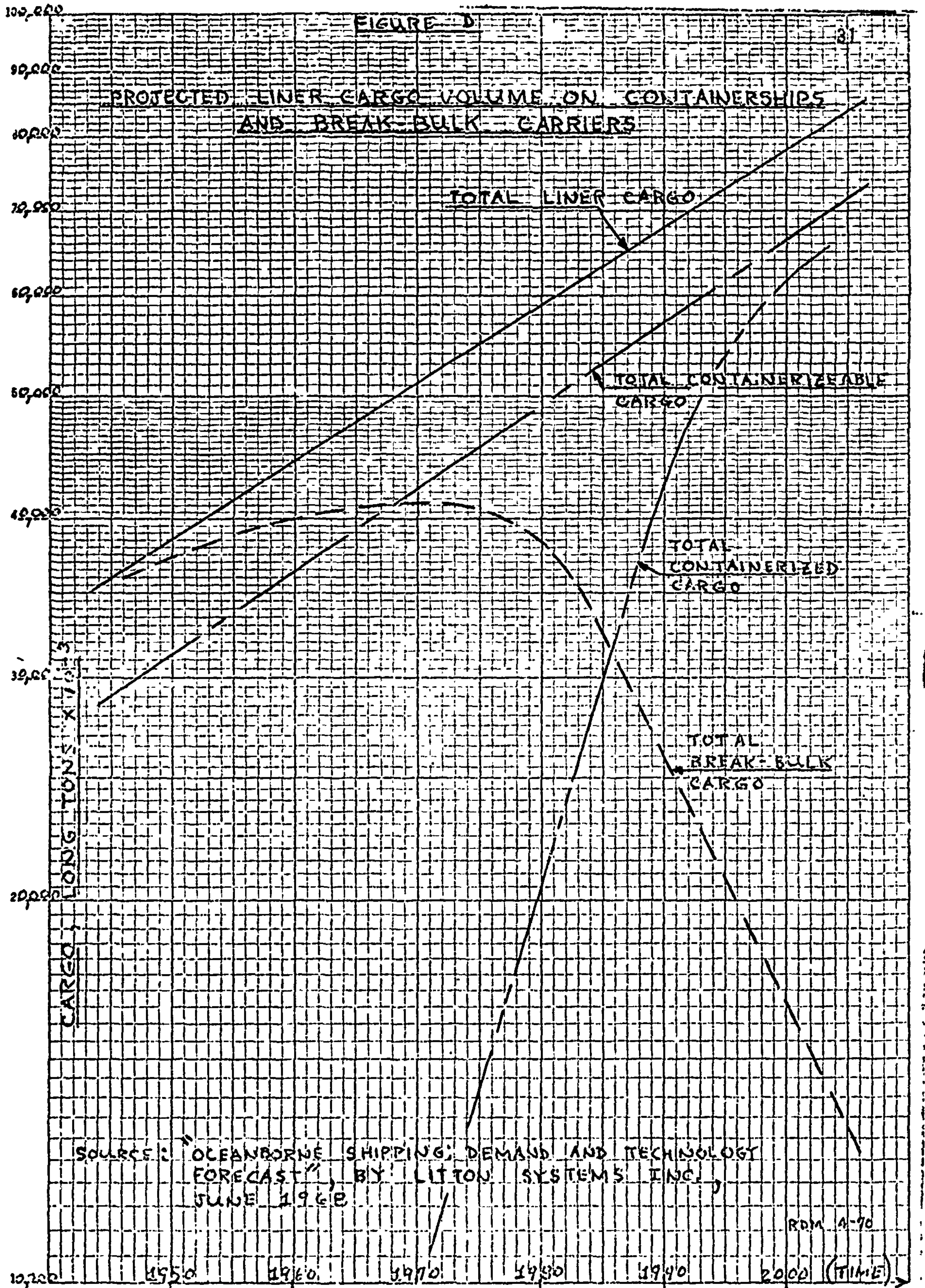


FIGURE D
31
PROJECTED LINER CARGO VOLUME ON CONTAINERSHIPS AND BREAK-BULK CARRIERS
TOTAL LINER CARGO
TOTAL CONTAINERIZEABLE CARGO
TOTAL CONTAINERIZED CARGO
TOTAL BREAK-BULK CARGO
SOURCE: "OCEANBORNE SHIPPING: DEMAND AND TECHNOLOGY FORECAST", BY LITTON SYSTEMS INC., JUNE 1968
RDM 4-70
CARGO, LONG TONS X 10^3
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
1950
1960
1970
1980
1990
2000
(TIME)

features. For instance, average capacity per new freight car in 1967 was 81 tons, or 50 percent greater than the cars retired. Cars of 125-150 ton capacity are now being used in rail service, and tests are being made with articulated cars having capacities of up to 250 tons. Railroads have found the combination high-volume, low-rate characteristics of such cars help meet the severe competition from highway and water carriers.

The trend for biggness has not been confined to hopper cars. Chemicals are being transported in special insulated 125-ton tank cars. Hot sheet steel is being moved in huge special gondolas. Special auto-rack cars with three decks have been put into service that can handle up to 12 standard or 18 small autos per car, thus permitting the movement of an entire fleet of autos in a single unit-train.

The general-purpose box car is being jumboized. One 90-ton model not only handles far more freight than previous box cars with less than half that capacity, but also is equipped with all-door sides for rapid loading/unloading of bulky freight such as lumber.

The degree of the trend in "bigness" in freight cars is only limited by factors, such as the need to maintain proper clearance for passing trains, and the physical restrictions on the railroad's right-of-way, i.e., narrow tunnels, low highway overpasses, sharp curves, or rail bridges that require reinforcing. Unless a connecting railroad has similarly cleared its right-of-way, standardized the interchange or there is agreed upon standardization on the size for jumbo cars, the jumbo cars will have to be confined to on-line traffic movements for one road.

The need to "standardize" will become more important as the variety of jumbo cars increases to fit specialized shipper needs.

2.2.5 Technological Trend For Trucks

Trucks have become very competitive because they are the most flexible freight transportation ·ode with their ability to operate "door-to-door" for short and regionally hauled commodities. New truck technology should enable the trucking industry to continue this competitiveness. Complete attainment of the benefits to be gained by technological improvements for trucks, however, depends on the introduction and acceptance of policy

rule changes and uniform nationwide operation standards. This would permit heavier and wider loading capabilities, i.e., axle loads from 18,000 lbs. to 22,400 lbs.; and vehicle widths from 96" to 102", thus accommodating 4' modular loads side-by-side within van containers and other large size special loads. There is a strong relationship between these changes and highway construction costs which must be considered during policy development. In addition, more powerful engines will probably be developed. They should be principally turbine, in the 280 to 720 hp. class, with dual fuel consumption capability to allow for operating either in city or country depending on pollutant restrictions. These large engines will permit possible triple bottoming* or double bottoming freight loads for most longer haul trips. Specially designed vans which can carry specific "tough to handle" loads will become more predominant. Self-loading and unloading could eliminate intermediate cargo handling, transfers or the need for many storage areas. As a result of R&D efforts to perfect controls for NET type systems and autos on automated highways, trucks may also be able to operate with automated controls. Trends in heavier load carrying capabilities will be constrained, however, by the improvements actually introduced into the load carrying

*Tractor unit plus three trailer units.

capabilities of roadways, bridges, etc. which must bear the weight of increased truck carrying capacities.

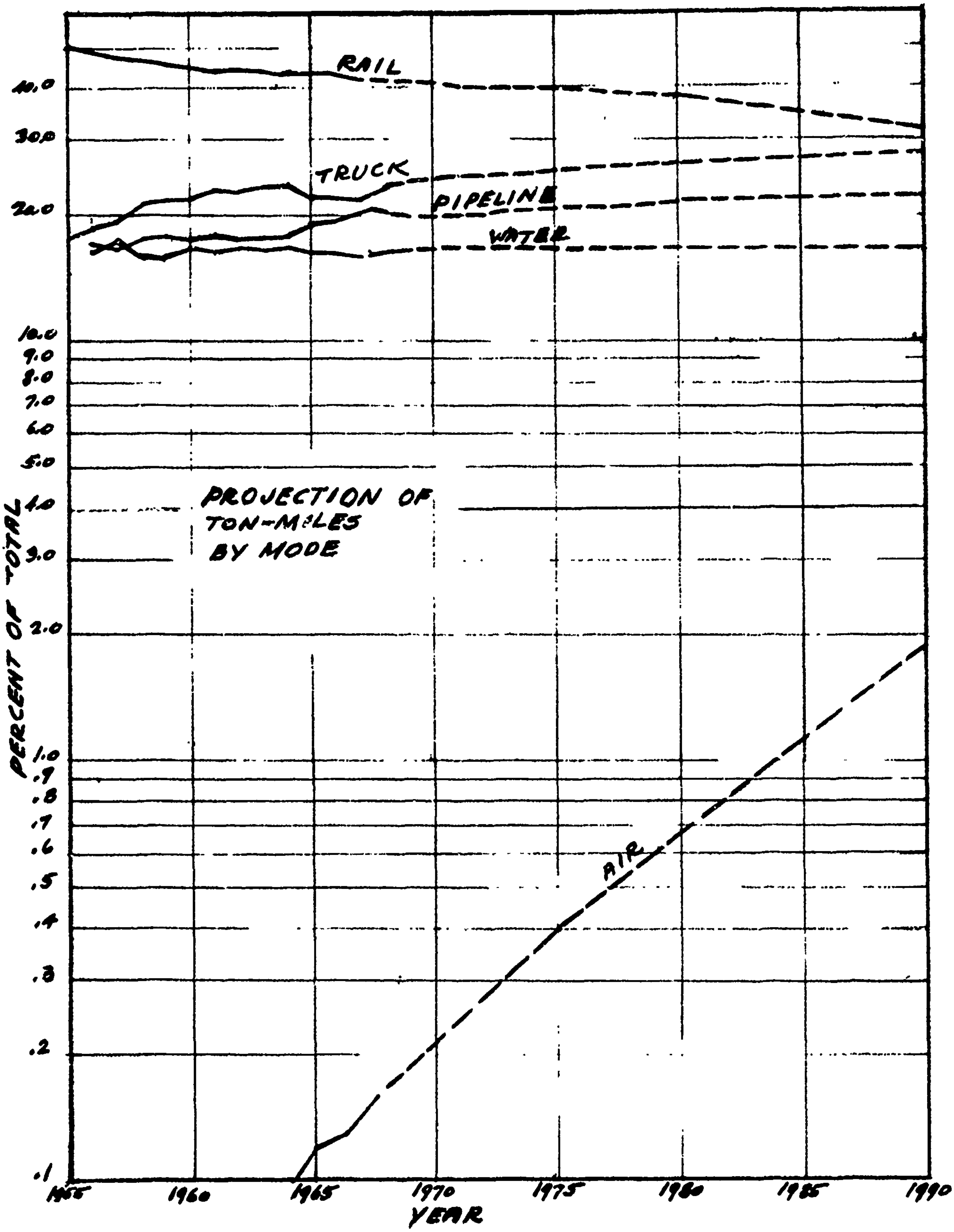
Finally, Figure E shows the trend of trucking to capture more of the market in which it operates. If the technological improvements and weight carrying policies cited above become reality, and the railroad industry is not able to offset their own downward trend, then the projections cited in Figure E for trucks increases significantly.

2.2.6 Technological Trend For Surface Effect Vehicles

There has been considerable research on surface effect or air cushion vehicles which literally ride over any relatively smooth surface on a cushion of air - an inch or less for land versions to a few feet or more for seagoing versions.

All types of such vehicles are being tested. There are configurations such as free moving vehicles over all types of relatively smooth surfaces, two-directional vehicles on fixed roadways or tracks, and even suspended vehicles in large pipelines. The advantages of such vehicles is their ability to operate over any kind of relatively smooth surface or through a pipe without depending on conventional wheels or float mechanisms for major guidance or support.

FIGURE E


RAIL
TRUCK
PIPELINE
WATER
AIR
PROJECTION OF TON-MILES BY MODE
PERCENT OF TOTAL
YEAR
1955
1960
1965
1970
1975
1980
1985
1990

Their basic development has lagged in the United States, but has progressed more effectively in Great Britian and France. These countries have focused attention on surface effect ships and air cushion track trains respectively. While major emphasis has been on the use of air cushion vehicles as a high-speed passenger carrier, consideration for their possible future use as open-sea containerships is also being studied. This whole class of vehicles may be the next new mode of transportation provided certain engineering difficulties can be overcome and their operation can be economically achieved. For surface seagoing ships, inherent instability in gusty winds must be controlled. For tracked versions of air cushion, noise levels must be kept low and tracks must be kept free from obstacles of larger dimensions that the air cushion, and gradients and curves must be kept to a minimum.

2.2.6.1 Tracked Air Cushion Vehicles (TACV)

Air cushion passenger trains (single car) have been under experimentation for some time. Small scale tests of "levacars" riding on a cushion of air about 5/8" above a rail and propelled by truboprop engines at a velocity of 150 mph. have been studied in the United States and Europe. Several public demonstrations of such vehicles can be expected within the next decade. If the anticipated breakthrough of linear motors occurs as is

expected, these Tracked Air Cushion Vehicles (TACV) may attain velocities of 300 mph. with a payload of 16 passengers. Demonstrations using modified versions of the turboprop driven air cushion vehicle carrying 100 passengers at 150 mph. for 300 miles can also be expected.

2.2.6.2 Surface Effect Ships

Air cushion passenger ships have been developed in Great Britian and are called "hovercraft". They are being used as a scheduled channel crossing service. The craft, 75' wide and 130' long, can carry 30 automobiles and 250 people over calm seas at 70 mph. Plans have been announced to use versions of the ship in early 1970 as a means for exploring and transporting supplies for expeditions along remote portions of the Amazon.

The United States has provided $1.2 million to test a 14 passenger air cushion ship in the San Francisco Bay area. The conclusion reached from the test was that such service is operationally feasible when it "can be performed primarily over water" and is economically feasible "only in special applications, such as on short, point-to-point routes, over relatively calm water,

connecting points generating large numbers of passengers who are willing to pay a premium fare, and for which alternative routes are more lengthy and time consuming."

The U.S. Navy has considered the use of Air Cushion Ships as an assault landing craft capable of riding 25 feet above the water and making 120 knots. Even if work began now, such a ship is at least 10 years away. But it could be the next big step in bridging the gap between air and surface ship freight transportation.

The concept of an open-sea, surface-effect cargo ship was studied by industry and government experts at the request of the Department of Commerce in 1965. The study focused on the technical feasibility of a vessel of 5,000 tons gross weight, capable of cruising at 100 knots and handling high-value containerized cargo. It was concluded that it would take three years, and cost $10 million, to determine the technical feasibility of the concept. Such a ship would be designed to operate at approximately five times the speed of

conventional cargo ships and twice that of hydrofoil vessels, provide point-to-point service at inland ports without the need of sophisticated port facilities. However, nothing has been done to implement the concept. At least $60 million is estimated to build a prototype, and the potential to carry large amounts of cargo is not yet apparent.

2.2.6.3 Tubular Travel

This is the concept of using a pipeline as the right-of-way for high-speed travel (400 to 500 mph.). Several variations for tubular passenger travel have been proposed. One, using the air cushion principle, has been experimented with at Rensselaer Polytechnic Institute. Scale-model vehicles, 12 in. in diameter, were propelled at speeds up to 125 mph through a 2,000-foot tube. Air forced through radial pads help suspend the vehicle a minimal distance from all sides of the pipeline. The vehicle thus "flew" through the pipeline and even banked around curves. A commercial size vehicle, however, 195' x 9' capable of carrying 200 people may be at least 20 years away.

The R.P.I. concept uses one engine to scoop in the air immediately in front of the vehicle, compress and eject the air aft through special skewed nozzles, which serve as a bladeless propeller. Braking is accomplished by cutting the forward jet, thus rapidly building up compressed air pressure in front of the vehicle. When the vehicle slows sufficiently, conventional sliding friction braking is used to bring it to a full stop.

2.2.7 Summary of the More Probable New Intercity Surface Systems

Ground systems under consideration as more likely candidates for replacing or adding on as new means for intercity travel have been categorized into five functional types.* These include a system involving modification of present rail facilities, a system involving construction of new right-of-way facilities, a new form of transport based on the use of guideways and air cushion vehicles, a concept based on use of electric linear motors and vacuum tubes and any system which automates motor vehicle travel. General desired or estimated operational and performance characteristics for such systems are noted below.

*These functional types were used as the basis for investigating new systems in the Delphi Exercise paragraph 3.2.2.

2.2.7.1 High Speed Rail System A (HSR-A)

This consists of intercity rail systems such as the Washington to Boston run where rail facilities are upgraded to allow the use of cars capable of travelling at speeds of 150 mph. In addition to roadbed and station improvements, the cars have a 64 passenger carrying capacity, have an onboard self-propelled capability and may be used as multiple unit trains. Cost of travel is estimated at 11.8 cents per mile for trips of 100 to 150 miles, longer trips costing less.

2.2.7.2 High Speed Rail System C (HSR-C)

This is a completely new 200 mile railroad servicing the seven largest North East Corridor cities and designed to provide 200 mile per hour service. This electrified system requires concrete slab and beam track supports to ensure proper rail alignments, reduced vibration and reduced maintenance. The 64 to 70 passenger vehicles may be used in 2 to 10 car trains. Fifteen minute headways between trains are contemplated. At a level of 5,000 million passengers per year, costs for 100 to 150 mile trips are estimated at 12.6¢ per mile. Higher utilization could serve to reduce these costs radically.

2.2.7.3 Tracked Air Cushion Vehicles

A TACV alternative to the HSR "C" has been considered on the same right-of-way. In lieu of a tracked roadbed, the system utilizes a U shaped concrete guideway which serves to provide fully automated travel by air cushion vehicles at velocities up to 300 miles per hour. Electric rails imbedded in the guideway could furnish power for the linear electric motor propulsion systems in each vehicle. Train lengths of up to five vehicles might be possible with 150 passenger vehicles supported on air cushions from compressed air provided by the electrically dirven onboard compressors. Costs for 100 to 150 mile trips are estimated at 13.4 cents per passenger mile.

2.2.7.4 Tracked Vehicle Tunnel System

Very preliminary analyses are available for a tracked vehicle system operating in a reduced pressure tunnel. The ultimate system may be one designed to allow automated travel by 44 passenger vehicles at 2 minute headways with velocities of up to 400 miles per hour. Linear electric motors would propel such ultimate vehicles on tracks in tubes with reduced air pressure.

Preliminary estimates indicate that passenger mile costs for 100 to 150 mile trips might be able to equal about 15 cents per passenger mile, but several major technical problems such as braking, exact stopping, tunnel track resistance to track misalignment from extreme changes in temperature, seals, general maintenance problems etc. have to be overcome before such systems can become economically feasible and competitive.

2.2.7.5 Auto-Pallet Vehicles

This is a system for automating motor vehicle intercity travel. A motor vehicle is bodily transported on an enclosed pallet moving on railroad beds at velocities of up to 150 miles per hour. The pallet could also be hung to an overhead rail. In either case, pallets would be automatically propelled and guided, air conditioned for comfort, and carry their own electric propulsion system. Initial estimates indicate that the cost of operating a pallet might be on the order of 16 cents per mile. Assuming current ratio of 2.1 motor vehicle passengers for intercity travel, this would be equivalent to 8¢ per passenger mile.

2.3 Waterway Modes

2.3.1 Passenger

The use of conventional displacement ships for moving intercity passenger travel is nominal, less than 1 percent of the total

intercity travel. A change seems very unlikely. The airlines have a major share of this market and they are continuing to absorb more. Overseas passenger travel on U.S.-flag ships except for cruises has practically been discontinued. This plus, in general, the high shipbuilding costs in U.S. yards makes the conventional ship mode the least attractive option to improve intercity passenger movement irrespective of the distance. Any major changes that do occur will probably come as a by-product of technological change to improve freight service.

2.3.2 Freight

The Transportation Association of America makes the following points. The vast majority of the nation's foreign exports and imports continue to move by ship.* Domestic water carriers collectively constitute the second largest mode of freight transport, in terms of intercity ton-miles. However, the latter's total freight volume has grown only moderately during the past 10 years, resulting in a drop in their share of overall intercity ton-miles from 30 to 25%. The preponderance of this

*Primarily overseas exports.

water carrier traffic -- 79% for domestic and 72% for foreign carriers -- falls into four categories: petroleum and petroleum products, coke and coal, iron ore and iron and steel, and grains.

U.S. domestic water carriers can be broken down into three categories: Coastwise carriers: these account for about 62% of water carrier ton-miles, and are holding annual traffic volumes level despite sharp oil pipeline competition. Barge lines: these account for about 23%, are the only group with an upward trend in traffic - 50% increase over the last 10 years. Great Lakes' carriers: these account for about 15%, experience sizeable annual traffic volume fluctuations, which seem to vary with changes in steel production. A bar chart distribution of this information since 1958 is shown in Figure E-1.

Intercity Freight Ton-miles

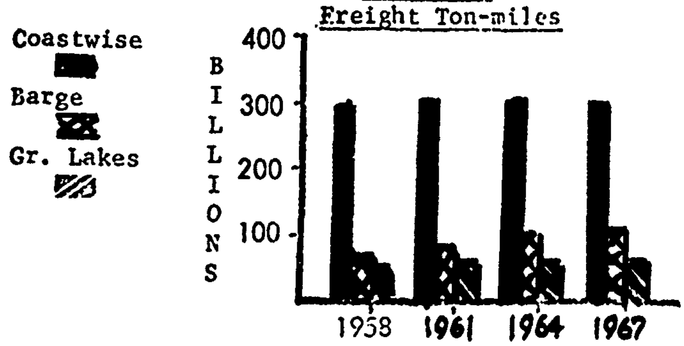


FIGURE E-1

Source: TAA

As in all freight service technology, the technological trend is to provide "bigness" and economy of scale.

2.3.2.1 Barge Trend

Barge drafts have probably stabilized at twelve feet 'n order to maintain present channel depths and not upset the waterways ecological balance. However, since the horsepower of towboats is increasing (e.g. 9,000 HP.) a larger number of barges can be pulled by 1 tow.*

The t- nd will be to make more waterways, channels, locks etc. adaptable to larger and larger integrated tows.

Innovations to assist in the pulling of large tows can be expected. Items such as special bow boosters to maneuver long tows into locks and negotiate tight bends in rivers and also the use of "box-type" barges which when integrated behind raked-end lead barges permit a smooth, less resistant flow through the water will be tried.

---

*A standard towboat with the cited HP. could pull at least 40 (35' x 193') barges carrying a load of 40,000 tons at speeds of 15 knots or better.

Finally, barges like rail freight cars and truck vans can be expected to be built for specific commodity hauls.

2.3.2.2 Great Lakes Shipping Trends

In all likelihood the displacement-type ship floating on the surface will continue as the predominant vehicle* for waterborne commerce in the Great Lakes and elsewhere for at least the next 50 years. More exciting types may carry some passengers, particularly in short ferry service, but as described in paragraph 2.2.6.2 they offer little promise of economic viability in cargo transportation. However, in order to keep freight shipping costs down and in competition with other modes, overall changes in ship designs can be expected by using some of the following innovations:

- Increased Beams - Making greater use of self-unloaders.
- Adaptability to Lake and Ocean - Making use of removable holds. These could be unbolted, or otherwise uncoupled, to allow a shortened ship to operate in salt water during the winter season or duirng periods of depressed business activity on the Lakes.

---

*Oceanborne Shipping; Demand and Technology Forecast, June 1968, DOT.

- Wave Suppression - Making use of systems to suppress hull-generated waves; permitting movement through rivers at high speeds without damaging shore property.
- Maneuvering and Propeller Systems - Making use of devices such as steering Korte nozzles*, Motora braking rudders, cycloidal propellers, bow and stern thrusters, forward as well as side thrusting controllable pitch propellers and Leitrad propeller system**.

2.3.2.3 Containerized and Barge-Carrying Ships

U.S. water carriers expect sharp traffic gains from new container, roll-on/off, barge-carrying, and assembly-line bulk ships.

A 3-deck barge carrying oceangoing giant 875' in length and 106' in beam is already under construction. These large ships are being built to carry about 38 barges (97' x 35') which can be loaded and unloaded by the ship's stern elevators. These barges, which can carry

---

* A tubular housing around propellers forming into a nozzle.

**The Leitrad propeller system is a free-turning propeller mounted abaft the regular propeller, larger than it and opposed to it in pitch. It obtains energy from the rotational momentum of the propeller race and converts it into added thrust - applicable to service on Lakes, where propeller diameters are limited by shallow draft requirements.

cargo containers, when placed aboard the giant haulers become containers too. While these freighters may not come into the seagoing inventory before 1975, they point to the need for concurrent development of improved automated means to load and unload them. For instance, these giant "Seabees", operating as a containerhsip with a crew of 38, could handle over 1,200 containers loaded in the barges, or nearly 1,500 if those carried on the upper deck were not in barges. A ship could be designed also as a roll-on/roll-off without modification or it could be made to handle special heavy-lift cargo of up to 2,000 tons, with its deep tanks carrying 15,000 tons of liquid cargo. To keep loading and unloading time competitive with other smaller sized ships, (at least less than 20 hours, perhaps 10 1/2 hours), requires the use of automated and systematized port procedures.

The major technological development in the maritime general cargo field today is the diminished use of conventional breakbulk lift-on/off freighters and the institution of a smaller fleet of container and roll-on/off ships. The prediction is that the maritime fleet of

fleet container carrying vessels will also move to "largness" just as is predicted for the train industry to use unit trains and the truck industry to use double bottoming and triple bottoming vans. The larger containerships will be designed to handle as many as 1,000 "standard" 20-ft. containers, although considerable disagreement still exists over what is the best standard. Efforts to promote standardization find subsidized lines favoring 8' x 8' x 20'/40' units and others favoring 8' x 8 1/2' x 24'/35' units. General cargo seems to be moving toward shipment by straight containerships but hauling for such bulk items as needed by DOD still favors the roll-on roll-off ship of at least 25-knots-14,000 ton capacity. The 70's will probably see a little of each depending on the funds made available for maritime proposals.

2.3.2.4 Nuclear-Powered Ships

While the trend toward us of nuclear-powered ships has continued in the U.S. Navy for vessels such as aircraft carriers, cruisers, and submarines, this has not been the case of merchant ships.

The U.S. took the nuclear shipbuilding leadership in 1961, building the SAVANNAH at a cost exceeding $80 million. The commercial utility, however, of a nuclear ship over a conventional ship has not been accepted. While nuclear propulsion can provide sustained speeds of 30 knots or more, and the productivity of two nuclear ships is greater than the productivity of three conventional ships, their disadvantages apparently outweigh their advantages. For instance, the cost of such ships (about $35 million each) requires U.S. subsidization for both construction and operations. This is a major roadblock. In addition, the need for special training of the crews, manning agreements, and the agreement among nations to permit such ships to enter their ports makes them commercially unattractive.

2.4 Pipeline Mode

The pipelining technology stems from the petroleum industry but pipelining is not a new mode of transportation. It has been known since the times of ancient Greece and Rome. It was introduced in the U.S. about 1865 to move oil in Western Pennsylvania five miles through a 2 inch line.

An interlinking network of nearly 200,000 miles of oil pipelines crossed the U.S. in 1965. This compares with 225,000 miles of rail line, 265,000 miles of major intercity and interstate highways,* and 30,000 miles of navigable inland waterways. Pipelines are normally buried and, with the exception of an occasional pump station or terminal, they deliver their cargo inconspicuously, reliably, and economically, (~ $.03/ton mile). The trend is toward use of larger diameter pipe and improved automated pumping operations, which encourages the use of this service at an increasing high volume and continued low cost.

The pipelining industry has been gaining 1% per year of the national intercity freight ton miles. Their growth is represented by Figure E-2.

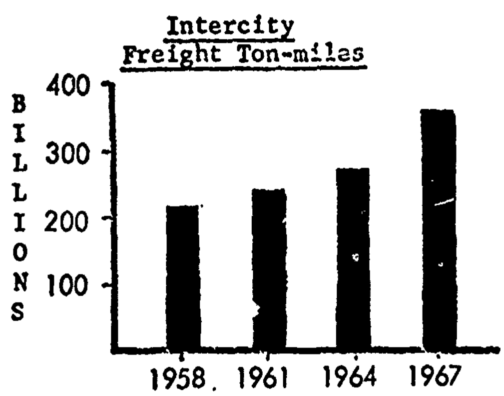


FIGURE E-2

*This includes main highways and streets of the Federal-Aid primary system, including interstate highways.

At present, the gross revenues of the industry are over $1 billion and expected to grow as well as influence the strong use of pipelines to move other solid commodities, wherever the terrain is rough, heavily wooded or swampy. (In such situations it is usually much more costly to construct a rail line or lay a roadway.)

There are two modes for moving solids through pipelines. One is in the form of a slurry using water as the propellant with the commodity directly immersed into the propelling liquid. The other is in the form of capsules which completely cover the commodity and protect if from interacting with the propellant, usually water or petroleum. Canada has, because of its terrain situation, made more progress and use of pipeline for moving commodities, other than oil (Figure F).

Long Distance Movement of Solids by Pipelines in North America

	(Billions of Ton-Miles)	
	1965	1980
Canada	0	5·6
U.S.	<0.1	3·5
Total	<0.1	8-11

FIGURE F

Source: SRI

By 1980, solids pipelines are expected to be to transport about 8 billion ton-miles per year of bulk materials, principally products of mines and forests.

2.4.1 Slurry System

The movement of various solids such as gilsonite, limestone and sulphur through pipelines over short distances is not new in the U.S. Shipping commodities other than oil long distantces, however, is relatively new in the U.S. As a result of R&D now in progress, the next decade should see the commercialization of a number of long distance slurry pipelines. The slurry systems that appear promising are: coal, sulfur, or potash in a water or petroleum medium; and wood chips or iron ore in water. In short, those commodities that can be finely crushed and mixed with a liquid propellant without contamination should become candidates for this transport system. The use of a particular slurry system will have to be decided on an individual basis, but operations should generally involve pipe diameters greater than 6 inches and solid volumes in excess of 1 million tons per year. Slurry preparation and solids separation will be key factors in choosing a type of slurry pipelines.

2.4.2 Solid System

A prototype of a system in which a commodity is encapsulated and propelled through a tube has undergone a series of tests in Canada, where winter weather and terrain pose special problems for conventional transportation methods. The Alberta

Research Council has already spent $800,000 and 10 years testing out the concept. The concept has not yet been proven commercially practicable. The tests and evaluations have been confined to a particular type of container; a 514 lb. steel cylinder of 16 inch diameter, traversing a 109 mile path at 2 mph. More research is required to determine the best size and shape of capsules and to determine loading and discharging facilities, best propellants and capsule backhauls.

The key to high utilization of this mode will depend on its ability to attract high volume movements of commodities such as grain at low cost. The low costs may be achieved by a high use of automatically controlled pumping and associated operational devices.

As to slurry vs. solid system pipelines, the latter seems to have advantages such as lower power requirements to suspend and move the payload, less need for pre-shipment preparation, and less need for drying the commodities at destination. By 1980, "unit trains of capsules" moving between Canada and the U.S. may well exist.

3.0 Technological Forecasting Methodology

3.1 General Discussion

A main emphasis of the technological forecast is to be able to provide a prediction of not only what technological innovations may lie ahead for transportation, but also to what extent these innovations might be used, and to what extent such use could contribute to undesirable effects on the environment in which they are introduced (e.g. noise, pollution and non-safety). The discussion that follows in this and subsequent paragraphs illustrates a methodology, i.e., a simulation, which is an attempt to provide the above insight at an aggregate level of detail for passenger modes of transportation.*

Future transportation systems not only have to compete with the service and performance capability of presently available systems, they must do better in some manner. Consequently, a means of describing systems to facilitate comparison has to be devised. There are several possible techniques, but those techniques that lean toward using quantitative procedures more than qualities have a greater facility for manipulation and precise comparison. The technique that has been selected is one of vector dimensions and for any system numerical values are developed to act as indicators

*At present, the methodology has not been extended to include freight systems beyond the development of the 1965 Commodity ton-mile data, Table 2-1, Appendix 2 The possibility to use it does exist with certain extensive modifications.

of its service and performance capability. The values are derived from linear programming, simple arithmetic additions and product multiplication procedures.

The values are arranged and ordered as components of a vector. These components are identified further as the characteristics or attributes of a system. For this report, the attributes used to effect comparisons have been defined and limited to the following general categories:

- the direct out-of-pocket cost to the user, and
- the indirect cost to society which is generated by the externalities from a system's use, such as: noise generation, pollution, land use and non-safety.

Other system parameters such as velocity, capacity, control, suspension and guideway needs are used in developing these values.

The forecast methodology uses these values in conjunction with a time value concept,* to compute an effective total trip cost for individual passengers or groups of passengers (2, 3 or 4) to make "portal-to-portal" trips. The trips are stratified according to trip length and mode of available service. The final output** is a modal*** split which depicts the probable choice of passengers to select one transport system over

---

* Time value concept is one in which it is assumed that individuals assign a dollar cost to the amount of their time expended in completing a trip. This cost accrues in addition to the cost that accrues as a result of actual out-of-pocket expenses (e.g. parking fees, gasoline, meals etc.).

** See Figures AA-1 through GG-2.

***In actuality it is more than a modal split because estimates for the use of systems within a given mode are made whenever a mode contains more than 1 system possibility.

another. This is determined on a round trip basis for specified trip lengths. It is calculated as the average, aggregated percent of the number of passenger miles that could be accounted for by each system possibility.

As shown in Table 1-1 1965 Passenger Data Base, 7 trip intervals were stratified and the possible modes of transportation that could be used in each interval are also defined. (Determination of the selection of modes to be used in any interval is discussed in paragraph 4.2.2.)

The number of passenger miles that can be expected to be generated over some trip interval, i.e., average trip distance, for a given year can be predicted. Also the cost/passenger-mile for any mode of travel can be estimated. By multiplying the percent passenger-mile factor that can be attributed to some system by the total passenger-miles expected and by the cost/passenger-mile, the total cost for using a system or a mix of systems over some distance interval can be calculated. Likewise, if the cost for some externality on per passenger-mile basis can be determined, the total cost resulting from that externality (noise etc.) being generated by some system's use can also be estimated. Finally, since the methodology allows for the manipulation of many of a system's variables (e.g. velocity, cost/mile, interface time, and time value), the sensitivity of the modal split

to variations can be appraised. Since technological improvements affecting transportation systems can be directly related to the attributes describing a given system, the possible effect of introducing new technology can be estimated, at an aggregate level, by varying selected attributes. For instance, by assuming the introduction of a new system with all the same attributes as an automobile except that its interface time is an order of magnitude less than the automobile, the effect on a modal split for any distance for any time span, from 1965 to 2000, can be quickly evaluated. Likewise, the capacity of some system can be limited and the shift to other modes (i.e., transportation systems) can be observed. In this way, not only can an initial estimate of the utility of a proposed technology change be made, but also various experiments can be run to determine where some aspects of technology ought to be supported to improve system performances.

4.0 Technological Forecast - Methodological Detail

4.1 Data Base Tables

Paragraphs 2.1 through 2.4 describe, in general, qualitative terms, the transportation systems and technology that might occur in the future. In order to place these new systems in proper quantitative perspective with those that are presently available as well as to form a data base for forecasts, the nation's transportation market was divided into two categories: passenger and commodity movements.

For each category, 1965 Base Data Tables were compiled (e.g. Table 1-1 1965 U. S. Domestic - Passenger-Miles; Table 2-1 - Commodity Ton Miles)*. Data in each chart was stratified as a function of trip distance interval as well as the mode of transport. The headings of the chart columns correspond to the factors discussed in paragraph 3.1. They contain data about present as well as future system possibilities. The future systems that are defined are representative of a generic, functional class of systems described in earlier parts of this report.

A large number of transportation system proposals were examined and evaluated as to their technological possibility and practical utility by various DOT organizations. Some of the proposals were found to be less attractive than others. In preparing Table 1-1** only those systems which had technology that has been under active consideration for some study or support by a DOT agency was included. All the systems, those available today as well as those proposed for the future, were assigned to specific trip distances. Each system was assigned to various trip distances, strictly on the design purpose of the system. Several systems appear in several trip distance stratifications. The automobile appears in all.

---

* Appendix 1 describes in detail the construction of Table 1-1 specifically: the derivation of the column headings, the scope of the definations and the development of the numbers used. Appendix 2 describes the same type of information for Table 2-1, 1965 Commodity Ton-Mile Data. 1965 was selected as the base year because of the availability of data to provide control totals for passenger-miles and commodity ton-miles.

** As noted in paragraph 3.0 the forecasting methodology developed to date has been applied only to passenger movement. The ensuing discussions consequently explain only the passenger transportation application of the methodology unless stated otherwise.

There are other advantages for using trip distances as a major segregating factor. For one, readily available data could be easily reaggregated as a function of trip length. This was considered better than trying to decompose available data or collect new data as a function of a specific origin and destination pair*. For another, profile biases that occur as a result of trips generated in one part of the country as opposed to another could be counter balanced implicitly. Finally, a time-value modal split concept used in conjunction with trip lengths had a better facility of predicting the use of future transportation systems than any other method, given the state of available aggregated data.

Consequently, the chart serves several purposes. First, it provides a systematic grouping of old and new systems. Given a specific future date, the selection of these new systems to use to form a mix with those already available is determined by the use of the "Delphi Technique"**.

Secondly, the chart provides a formatted output and tabularization of results from which totals of transportation costs, passenger-miles

---

* Only a paucity of origin and destination data exists that is unconfounded and useable for modal split analyses.

** Bright, J.R. ed. Technological Forecasting For Industry and Government - Methods and Applications, Analysis of the Future the Delphi Method, Olaf Helmer pp. - 116-134, Pretice Hall Inc., Englewood Cliff, New Jersey, 1968.

etc. can be calculated. At the heart of the methodology is the ability to derive system choices. These system choices can be described in terms of expected passenger miles/mode. Given the system cost/passenger mile for some specific externality (i.e., noise, or pollution) the total cost attributable to a system at some distance or over all distances is calculated by a simple product computation (cost/passenger miles x passenger-miles).

Thirdly, the format of the chart is compatible to computer programming, that is, the chart can be printed by a computer. Consequently, input data changes are easily accommodated and new control totals quickly determined. Chart 3 is an array of data for the average number of travelers on any particular mode. This information can be rearranged and new charts developed showing data for system splits (i.e., modal splits) for 1, 2, 3 or N people traveling as a group with specific time value assumptions per individual. Effects on modal choice as a function of group size is discussed in paragraph 4.3.7 Figures AA-1 through GG-2 graphically show the effects.

4.2 Delphi Methodology

4.2.1 Delphi Technique - Background*

The Delphi technique grew out of the need to develop a methodology that could assist in predicting future outcomes

---

*Bright, J.R. ed. Technological Forecasting For Industry and Government - Methods and Applications, Analysis of the Future the Delphi Method, Olaf Helmer pp. - 116-134. Pretice Hall Inc., Englewood Cliff, New Jersey, 1968.

of events when no other precise means seems to exist to determine such outcomes objectively or quantitatively.

The technique attempts to make effective use out of intuitive judgments and considered opinion of well informed individuals. The "well informed" individuals should make up a group of people, (a panel of at least 9-10) who have been involved not only in detail study, analysis or manufacture etc. of natural precursors to the event but also understand the policy and societal impacts that the event can have. These are often difficult to quantify.

The technique is used as follows: The panel is polled for its opinion on possible outcomes of a particular event. The event is well specified and the assumptions clearly defined. These opinions are requested in quantitative terms, either as a probabilistic measure or as normal counting number.

The results are pooled and distributions developed so that central tendency statistics (e.g., means and variances) can be calculated. The distribution statistics are recycled to all respondents to adjust their submissions, reinforce their opinions or volunteer explanations if their replies seems to be at great variance with the group's consensus.

The technique derives its utility from the realization that projection in the future, on which public decisions often must rely, are in fact based on the interaction of many variables the least of which is personal expectation, behavior, serendipity and general politico - societal needs. An established theory to handle such interaction or to quantify such relationships doesn't exist and because of the dynamism involved may never exist. The more uncertain one is about the possibility of outcomes, the more useful the Delphi Technique may be. At the very least, it produces a consensus of expert opinion and focuses attention to discrepancies that should be researched.

4.2.2 Delphi Exercise:

In order to achieve an insight with respect to the more probable passenger transport possibilities and their R&D dollar requirements from 1970 through 1990, the Department of Transportation solicited expert industrial, academic, and scientific judgement on which future transportation technologies,* through 1990, would be most probable, and what the research and development costs might be to achieve those systems at certain intermediate dates from 1970 to 1990.

*Future systems were divided into three system categories. They were Urban System; Intercity (Surface-Interurban) Systems; and Intercity (Air) Systems. Tables 1, 2, and 3 depict the performance characteristics of the systems that were determined as a result of the Delphi Exercise.

Table 1 NEW URBAN PASSENGER SYSTEMS CHARACTERISTICS

Characteristics	MAC-1 High Density CBD	MAC-2 High Density CBD	DIAL-A-BUS Local Neighborhood	PAS Local Neighborhood	NET-1,2 City-Wide 1 or 2 Mile Grid	NET-3 City-Wide 1 or 2 Mile Grid	FTL-1 Large Capacity Transit Link	FTL-2 Large Capacity Transit Link
Trip Length (Miles)	0-2.5	0-2.5	1-20	0-2.5	2.5-20	2.5-20	2.5-20	20-50
Block Velocity (avg. speed between stations)	8-9	8-9	13-18	16-18	50-70	50-70	100-140	100-290
Cost (¢/Pass-mile) (Based on Range expected max. pass/hour)	17.5	37.5	25.0	13.5	4.0	10.0	8.0	15.
ACCESS								
Av. Time (min.)	.15-1.0	.25-1.0	6	.5-1.5	5-10	3-8	10-60	10-60
Av. Distance (ft.)	50-200	50-200	0	50-125	.5 - 1 mi	.5 - 1 mi	0 - 10 mi	0 - 10 mi
Range Expected Max. Pass/hour	2000-8000	2000-2500	100-500	25-500	2000-15000	2000-15000	3200-40,000	40,000-64,000
Vehicle Capacity (Pass/Unit)	Conveyor	3	6-10	2-4	4-12	4	20-80 (1-10 car trains)	52 (1-10 car trains)
Propulsion and Power Supply	Electric Conventional Motor External	Electric Linear Motor External	Internal Combustion Engine Self-Contained	Electric Motor Self-Contained	Electric Motor External	Internal Combustion Engine & Electric Motor Self-Contained & External	Electric Linear Motor Ext.	Various Advanced Options
Control	Automated	Automated	Manual plus Automated Dispatch	Manual plus Automated Vehicle Storage	Automated Guideway Operations	Automated Guideway Operations & Manual	Automated Guideway Operations	Automated Tubeway Operations
Suspension Mode	Conveyor	Wheels	Wheels	Wheels	Wheels	Wheels	Air Cushion	Air Cushion
Right-of-Way or Easement (ft)	4-8	8	City Street	City Street	8	8	8-12	20 or Easement for Overhead, Underground

Abbreviations: MAC = Major Activity Center
PAS = Public Automobile Service
NET = Area Wide Network
FTL = Fast Intra-Urban Transit Link
CBD = Central Business District

TABLE 2 NEW INTERURBAN PASSENGER SYSTEMS CHARACTERISTICS

Characteristics	HSR - A High Speed Rail "A" Version	HSR - C High Speed Rail "C" Version	TACV Tracked Air Cushion Vehicle	TVS Reduced Air Pressure Concepts	AUTO-PALLET Auto on Individual Pallet
Trip Length (mi)	50-500	50-3500	50-200	50-200	50-3500
Block Velocity (mph)	104	146	190	290	130
Cost(¢/Pass-mile) (at design operating capacity)	11.8	12.6	13.4	15.4	8.0
ACCESS Avg. Time (min)	10-60	10-60	10-60	10-60	10-60
Avg. Dist. (mi)	0-10	0-10	0-10	0-10	0-10
Max. Systems Capacity (Pass/Hr)	12,000	15,000	12.000	10,000	5400
Vehicle Capacity (Pass/Unit)	64-70	126-132	150	44	2.1 (1 auto per pallet)
Propulsion & Power Supply	Conventional Electric Motor External	Conventional Electric Motor External	Linear Motor External	Linear Motor External	Conventional Electric Motor External
Control	Manual	Partially Auto.	Automated	Automated	Automated
Suspension Mode	Railbed Conventional	Railbed Conventional	Guideway Air Cushion	Tracked (Reduced Pressure Tunnel)	Railbed Conventional

Table 3 NEW AIR SYSTEMS

Year	Systems Characteristics	Helicopter	Light Aircraft	Light VTOL	Third Level Aircraft	STOL	VTOL	Subsonic Jet (Short Haul)	Subsonic Jet (Long Haul)	Supersonic Jet
1975	Capacity (seats)	30	6		40	90		125	200-350	
	Weight (Lbs.)	19000	5700		40000	67000		170000	400000	
	Avg. Utilization Dist. (Mi)	30	200		150	233		633	2167	
	Operating Range (Mi)	20-50	50-500		50-350	100-500		200-1500	1500-3500	
	Cruise Velocity (Mi/Hr, MACH)	195	200		350	M .65		M .89	M .85	
	Indirect Cost ($/Seat Trip)	4.80	0		4.50	8.15		6.96	19.50	
	Direct Cost ($/Seat Mile)	.16	.83		.03	.035		.011	.009	
	Break-Even Load Factor (%)	50			60	50		50	50	
1980	Capacity (seats)	90	6		30	150-200	75		200-350	280
	Weight (Lbs.)	72000	5200		40000	100000	57000		700000	675000
	Avg. Utilization Dist. (Mi)	40	200		150	233	233		1300	2333
	Operating Range (Mi)	10-100	50-500		50-350	100-500	100-500		200-3500	1500-4000
	Cruise Velocity (Mi/Hr, MACH)	220	250		400	M .8	M .6		M .95	M 2.7
	Indirect Cost ($/Seat Trip)	3.20	0		3.90	5.83	16.31		10.40	27.53
	Direct Cost ($/Seat Mile)	.08	.83		.026	.025	.07		.008	.0118
	Break-Even Load Factor (%)	50			60	50	60		50	50
1990	Capacity (seats)		10	6	60		120		500	300
	Weight (Lbs.)		8700	10000	50000		120000		1000000	900000
	Avg. Utilization Dist. (Mi)		200	200	150		200		1300	2833
	Operating Range (Mi)		50-500	50-500	50-350		50-500		200-3500	1500-5500
	Cruise Velocity (Mi/Hr, MACH)		350	250	500		M .6		M .98	M 3.2
	Indirect Cost ($/Seat Trip)		0	0	3.00		8.00		9.10	28.33
	Direct Cost ($/Seat Mile)		.83	.81	.02		.04		.007	.01
	Break-Even Load Factor (%)				60		50		60	50
2000	Capacity (seats)			9	70		200			300
	Weight (Lbs.)			12500	50000		175000			750000
	Avg. Utilization Dist. (Mi)			200	150		200			7000
	Operating Range (Mi)			50-500	50-350		50-500			7000
	Cruise Velocity (Mi/Hr, MACH)			350	500		M .85			M 5.0
	Indirect Cost ($/Seat Trip)			0	3.00		4.00			70.00
	Direct Cost ($/Seat Mile)			.54	.02		.02			.01
	Break-Even Load Factor (%)				60		50			50

It was assumed that each individual queried had as result of his experience a conceptual relationship between performance requirements, dollar requirements, and probable achievement capability. While the structure could not be written explicitly, it was, in effect, assumed to exist as shown in Figure G. Given the date and performance specification of either Table 1, 2 or 3, it was assumed that the points on Figure G could be derived

Thus the Delphi Technique consisted of sending to each expert whose judgment was solicited, a detailed performance description of each of a number of possible competitive future systems. Each individual expert then submitted his estimates of:

1. The probability of each system achieving a desired R&D system technical feasibility at a given date, and
2. The research and development costs to bring each system to the specified level of technical feasibility by the given date.

Each expert was encouraged to comment on the specifications sent to him and recommend changes which he felt would make them more realistic. The Department summarized all the estimates and comments and then resubmitted the summaries and a modified set of specifications on all the systems to the experts for a second round of estimates. This process caused the forming of

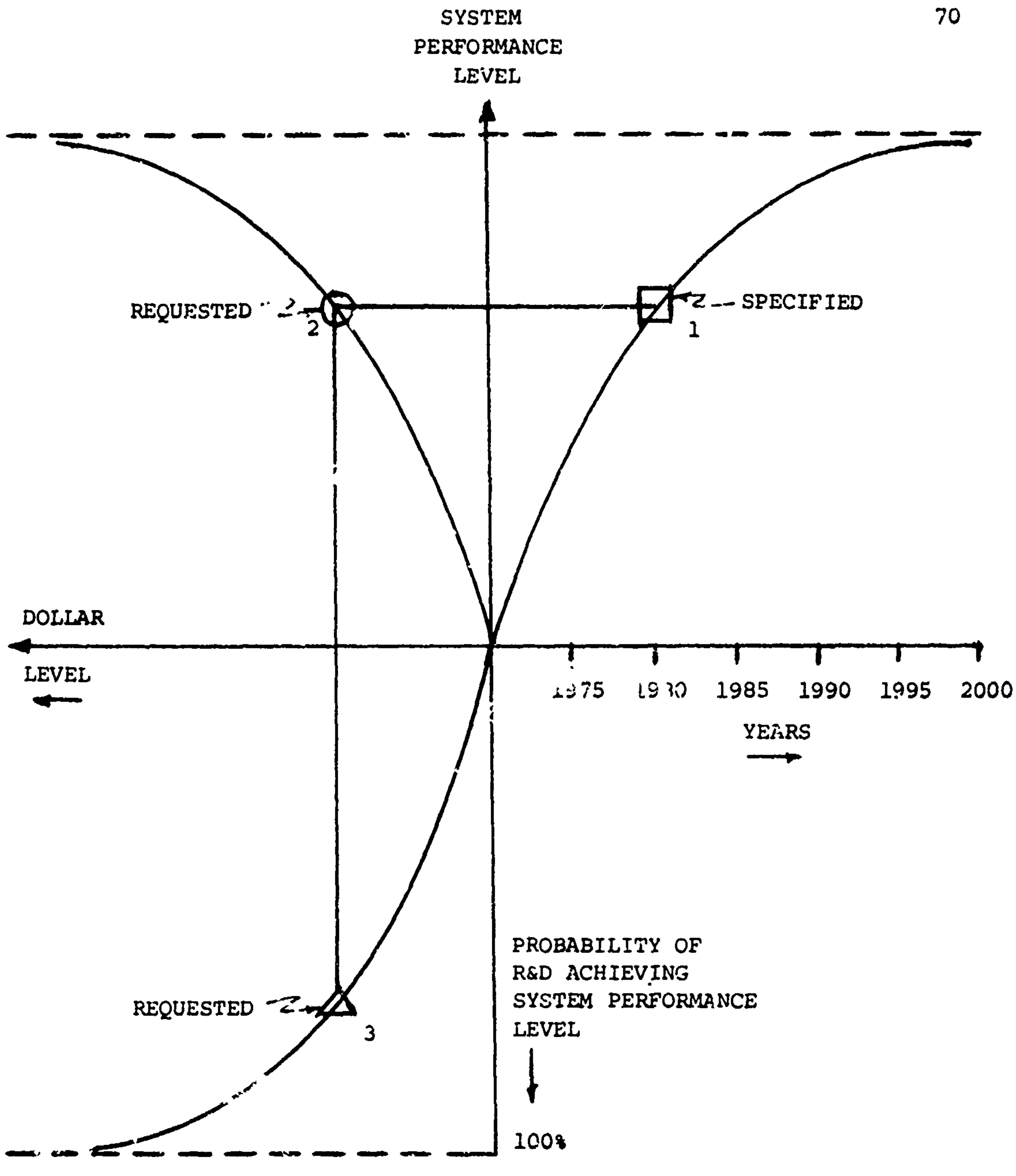


FIGURE G: SYSTEM RELATIONSHIPS ASSUMED TO EXIST FOR A DELPHI EXERCISE

a consensus on what their associated R&D costs might be.*

Thus the purpose of this exercise was two-fold. It provided cost and time estimates. The latter, as stated earlier, is used as the basis of selecting systems to mix with already existing ones in order to test modal split behaviors at some future date.

The Delphi questionnaires were structured "time-wise" so that the time period desired for testing in the forecast (i.e., 1975, 1980, 1990, 2000), were the time periods stipulated to the Delphi participants. Consequently, if the Delphi consensus determined R&D for a surface system could be accomplished by a certain date with probability $\geq$ .7, then it was assumed that the system could be implemented where needed after at most 10 years. The systems that met this criterion were used to form a mix of systems available for public use. However, for air systems it was assumed that the vehicles were available for implementation as soon as the probability reached the criterion level stated. No delay for implementation was required.

The criterion of a probability greater than or equal to .7 was arbitrary. It implied a better than average chance that events might occur as estimated. The number of participants was

*See Appendix 3 for the names of the participants and a presentation of the output (graphic and tabularized) resulting from this two cycle Delphi exercise.

purposely limited to 9 and 10* (the names of the participants are identified in Appendix 3). More participants might have made the results more precise but the trend might not have been significantly different.

4.2.3 Delphi Results:

Appendix 3 identifies the participants of the Delphi exercise and contains the results of two cycles of questioning. The information is presented in the following manner. First, for each of the 3 system categories, tabularized statistics of the means and variances of group responses for both cycles are presented. The same information is plotted in the set of graphs that follow the tabularized results. The graphs are organized as follows:

At the beginning of each category there are two plots of mean estimates for the system peculiar to a category. One represents the probabilities of achieving the R&D requirements by a specified year. This is the E(p) plot. The other represents a weighted average cost of achieving the R&D by the years specified. It provides the E($) plots.

---

*9-10 participants were determined according to a binomial statistical sampling procedure where not only a 95% confidence interval is required and a 20% accuracy in the participants estimate is expected, but also the probability of producing the same results if a universe of experts were sampled is at .9 (i.e. 9 out of 10).

The formula for these calculations for each specified time period is:

E(P) = Mean Probability

$$E(P) = \sum_{i=1}^{N} \frac{P_{ik}}{N}$$

where N = number of respondents
P_{ik} = Probability of the $_i$th respondent for the kth system. k=1,2,...,n.

S.D. = Standard Deviation for E(P).

$$S.D. = \sqrt{\sum_{i=1}^{N} \frac{(P_{ik} - E(P))^2}{N}}$$

AND

E($) = Mean Cost

$$E(\$) = \sum_{i=1}^{N} \frac{\$_{ik}P_{ik}}{\sum P_{ik}}$$

where $\$_{ik}$ = The dollar estimate of the $_i$th respondent to accomplish the R&D for the $_k$th system.

S.D. = Standard Deviation for E($)

$$S.D. = \sqrt{\sum_{i=1}^{N} \left[\left(\frac{\$_{ik}P_{ik}}{\sum P_{ik}}\right) - E(\$)\right]^2 \cdot \frac{P_{ik}}{\sum P_{ik}}}$$

Following the set of summary curves are plots of the means for each individual system and the variances (one standard deviation) about the mean as time into the future progresses.

One would expect that if technological requirements remain constant, the mean probability consensus should level off at a high value and the standard deviation (S.D.) for both probability and cost estimates should converge. For surface systems, this was usually the case. A lowering of the mean probability, however, did occur, e.g. HSR-A system, 2nd. cycle. This could indicate that if one waits too long to begin developing a system, technology will pass the system by and the chances of it becoming accomplished reduced. Likewise, a spreading of the S.D., especially in the cost of R&D, may indicate a serious participant inconsistency as to the degree of difficulty that has to be overcome before a new system can be achieved (e.g. NET; TACV; VTOL; subsonic and supersonic jet). Since the requirements for Air Systems keeps changing, a decrease in the probabilities of achieving the most difficult systems should be expected, but the convergence of S.D.'s should also occur. Nevertheless, note that the ratio of the S.D. to the mean is less for the air systems than for the others. In spite of the inconsistency of divergences noted, this ratio result seems to indicate that there exists a better understanding of what R&D is needed to achieve air vehicles then to achieve some of the future surface systems.

4.2.4 Delphi Implications

The Delphi system results can also cast an initial estimate of the competitiveness that might eventually exist between old and new systems. A more detailed forecasting methodology is the substance of the modal split explanation of paragraph 4.3.

As already noted in Tables 1, 2 and 3, the desired performance characteristics of the urban and intercity passenger systems considered are described. Those having a 70% or better chance of having their R&D requirements completed by 1975 and in initial operation by 1980 are shown in Figure H in terms of capacity and velocity. Those that can be developed and in initial operation (with the same probability) by 1990 are shown in Figure I.

The probable competition for similar markets is easily discernible. Note Figure H "New Passenger Service System Possibilities for 1980". It shows Public Automobile Service (PAS) systems, Dial-A-Bus Systems being in service, as well as new High Speed Rail (HSR), Short Take Off and Landing (STOL) and Subsonic Jet Service, the latter operating at a greater load carrying capability and cheaper cost than the present class of subsonic jets.

FIGURE 11: NEW PASSENGER SYSTEM POSSIBILITIES FOR 1980

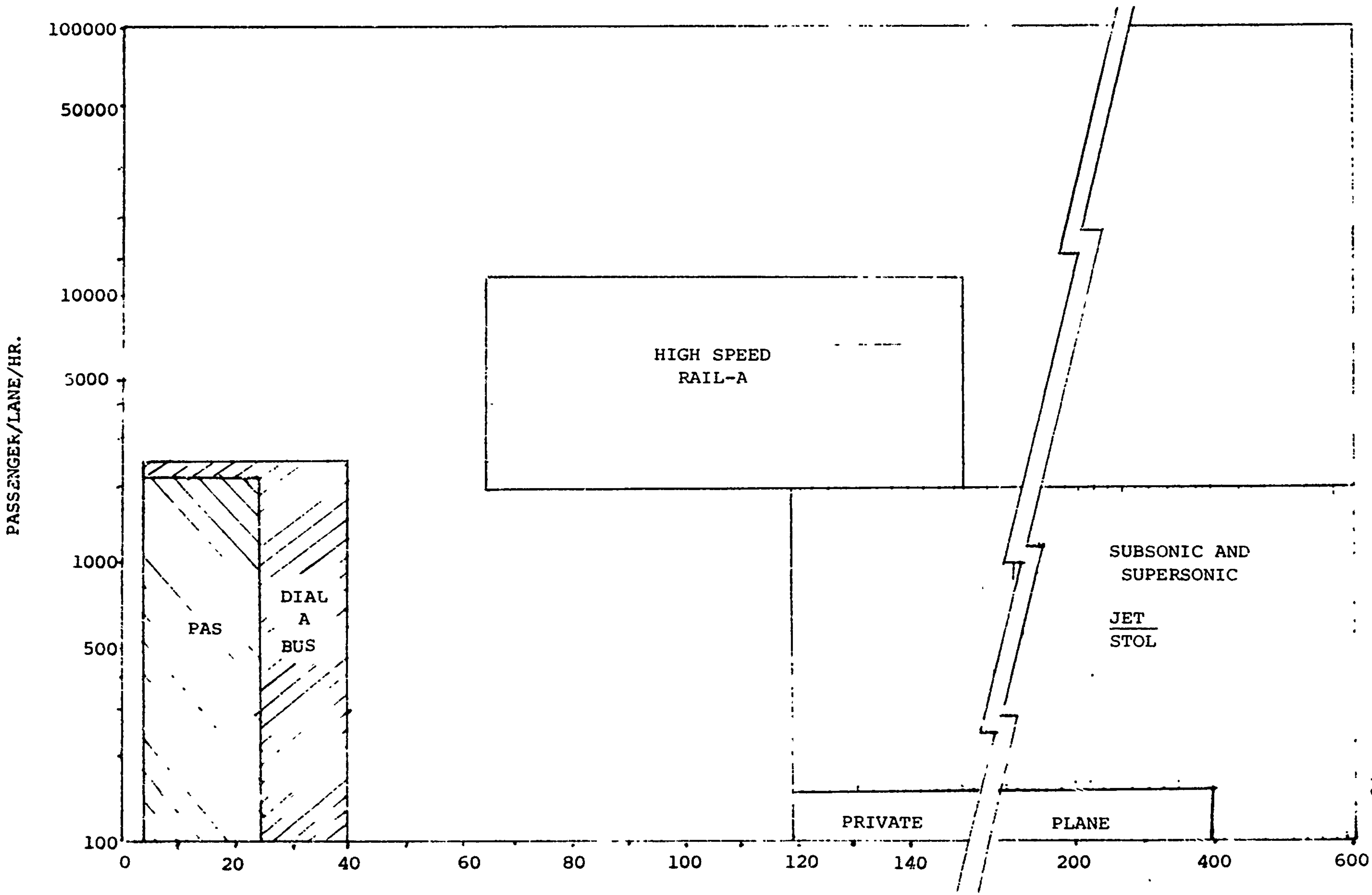
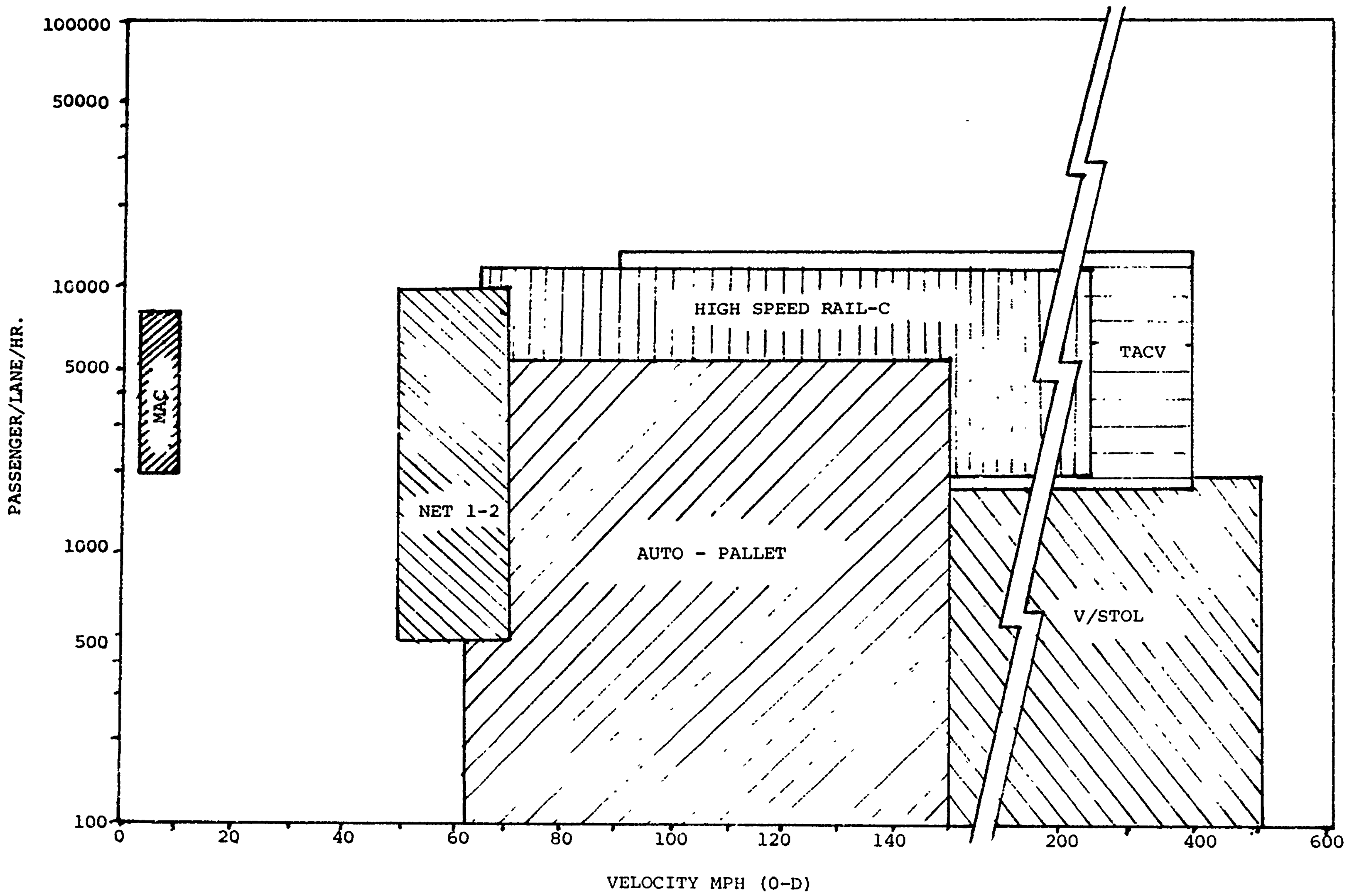


FIGURE I: NEW PASSENGER SY. ... SERVICE POSSIBILITIES FOR 1990



On the other hand, Figure I shows by 1990 the concentration for new systems shifting toward larger capacity passenger systems, moving people at greater velocity and convenience than available today. There seems to be a predominant cluster of new systems at velocities between 50 and 300 mph, such as NET 1-2 systems, and a smaller cluster of advanced continuous systems such as Major Activity Center (MAC) systems in high density centers. As stated earlier in the report, MAC is the generic term used to describe either fast pedestrian conveyors (MAC-1) or lightweight 3-passenger automated vehicles (MAC-2). They are designed to move people between office buildings, around shopping promenades, and through transportation centers such as air terminals. NET 1-2* is the generic term used to describe a class of city-oriented circulation and distribution type systems that consist of sets of independent loops of guideways with their own set of captured automatically controlled vehicles. Initial systems (NET-1) would contain no branching or switching capability but subsequent systems such as NET-2 would have this capability while future modifications systems would be extended to have a dual mode capability (i.e., ability to operate on city streets independent of the guideway as well as on the guideway proper).

*NET: is a symbol for Area Wide Network Transportation System. Around a city core the NET System's span is reduced and it has been identified as either a "People Mover or Personal Rapid Transit". Likewise between cities certain loops have been stretched and the system called either an FTL (Fast Transit Link) or an LH (Line Haul) System.

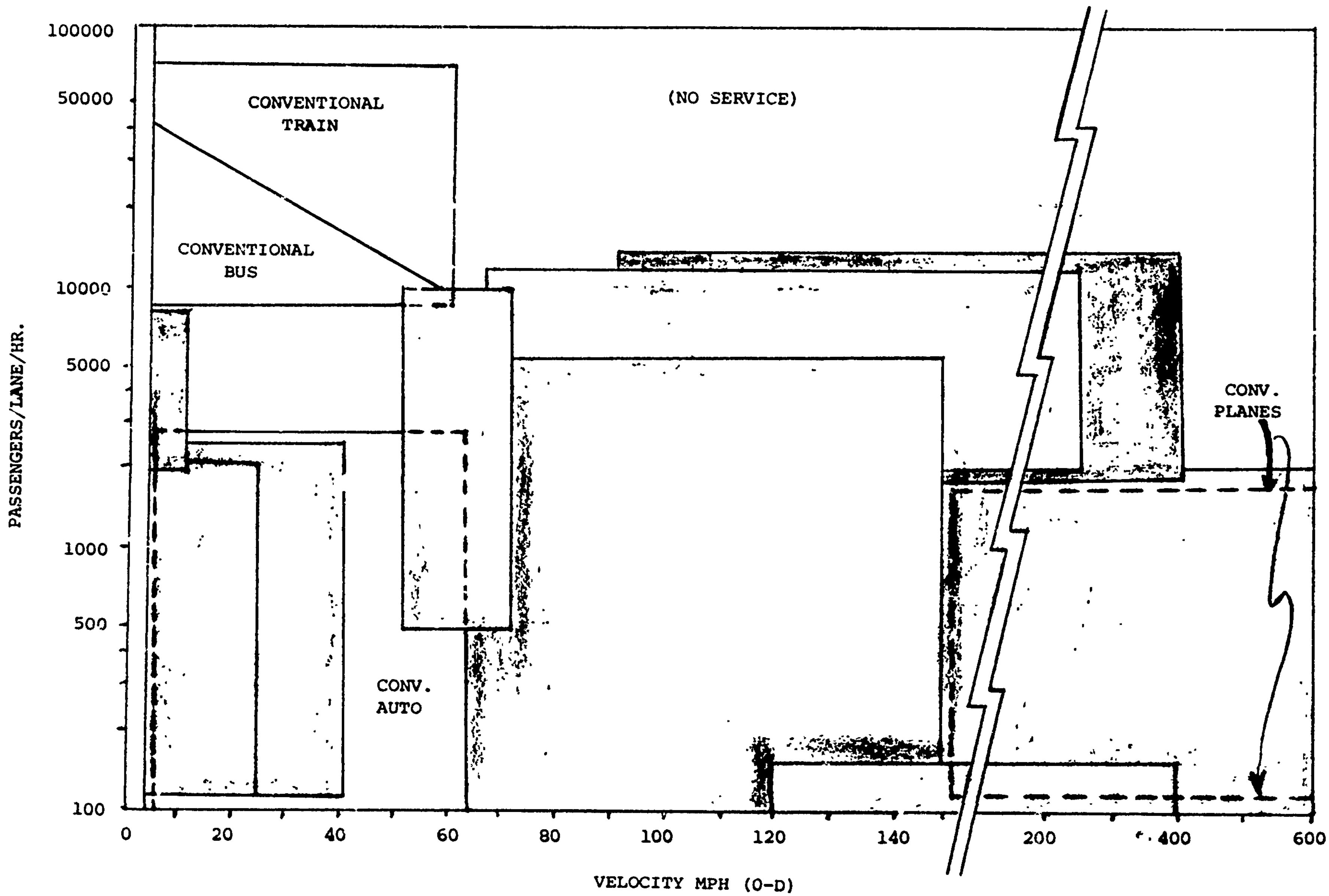
In addition, the compound-type helicopter, or V/STOL aircraft, having the landing and take off advantage of vertical aircraft, the cruise capability of conventional aircraft and the load capability of carrying better than 100 people would be vying for a major portion of the short haul air market. Finally, Figure J indicates how the possible systems of 1980 and 1990 (dark blocks) would probably compete with the conventional systems that are in service today. The overlap of service markets is apparent.

Many of the future systems are contingent on the development of intricate and sophisticated computer programs, capable of exercising automatic command and control as well as on the development and refinement of newly engineered vehicles. The computer programs would have to assure safe and reliable control of (1) vehicles operating on a network of guideways, or (2) pallets which in turn carry vehicles on a network of guideways. Initially designed for city use, such systems could be extended for regional use.

a. Urban Systems: By 1980, one should expect to have in certain locations (1) systems of conveyor belts moving at low velocities and suitable for up to 2.5 mile trips in congested downtown and terminal areas;* (2) Dial-A-Bus

*Some relatively short conveyor belt systems are in use at some transportation terminals today. These are the initial prototypes of MAC-1 systems. Also, grants for feasibility studies of entirely new rapid transit systems based on existing vehicle technology have been made to Seattle, Atlanta, Los Angeles, San Juan, Pittsburgh, and Baltimore. Pittsburgh, for example, is undertaking demonstration of the Skybus system, a 20-passenger vehicle using rubber tired wheels on guideways designed to permit velocities of 30 mph between stations.

FIGURE J: COMPARISO' PRESENT AND FUTURE SYSTEMS



Systems; and (3) the beginning of public autos for transporting passengers from urban fringe areas into the central business districts. Estimates for R&D costs, excluding demonstration costs ranging from about $20 million for the MAC-1 Systems to $8 million for the Dial-A-Bus and $10 million for the Public Auto System, except a much higher confidence of completion for the Dial-A-Bus seems to exist.

By 1990 one should expect to have some NET type systems in operation, providing two-way traffic, and competing with the conventional auto. They might be of small span for use in major activity centers, or several miles long, with or without intermediate stations. A traveler could route himself over the network. Many travelers would have to transfer between lines once or twice and would use two or three different loops and different vehicles during a NET trip. Since all cars on one loop would be traveling the same route, larger cars could be used between stations that have heavier traffic. Automatic control apparatus would switch cars into off-line stations, slow them, accelerate them again, merge them back onto the line, and maintain

their headways. In order to have operating systems by 1990, it is estimated that about $70 million would be required to complete the R&D by 1980.

b. Intercity Systems: By 1980, one could expect the use of 90 passenger capacity STOL aircraft as the forerunners of an eventual V/STOL system concept for the short haul intercity market. Light aircraft operating at 250 mph, costing the user approximately 83¢/vehicle-mile and carrying 6 people would also be available. For the air mode in particular, a strong consensus seems to exist that given adequate time, the industry has the capability of providing the service that the market seems to be demanding, i.e., bigger and faster aircraft in the subsonic jet area and bigger (with respect to capacity handling capability) in the lighter aircraft intermediary service area. Estimates for R&D expenditures to achieve the capabilities stated in Table 3 are in the range of $300 million for STOL; $346 million for the subsonic jets and about $26 million for light aircraft.

High speed rail versions are technological possibilities by 1980, but such systems as Tracked Air Cushion Vehicles (TACV) or Vacuum Gravity Tube Systems may not be available for market service until after 1980 for either technical or cost of operating reasons. Of the two, TACV has the greater

probability of being realized as a viable system. In general, the high speed surface systems will involve either modifying present rail facilities, or constructing new right-of-ways using guideways and relying on complete development of electric linear motors.

4.3 Modal Split - Time Value Forecasting Technique

4.3.1 General

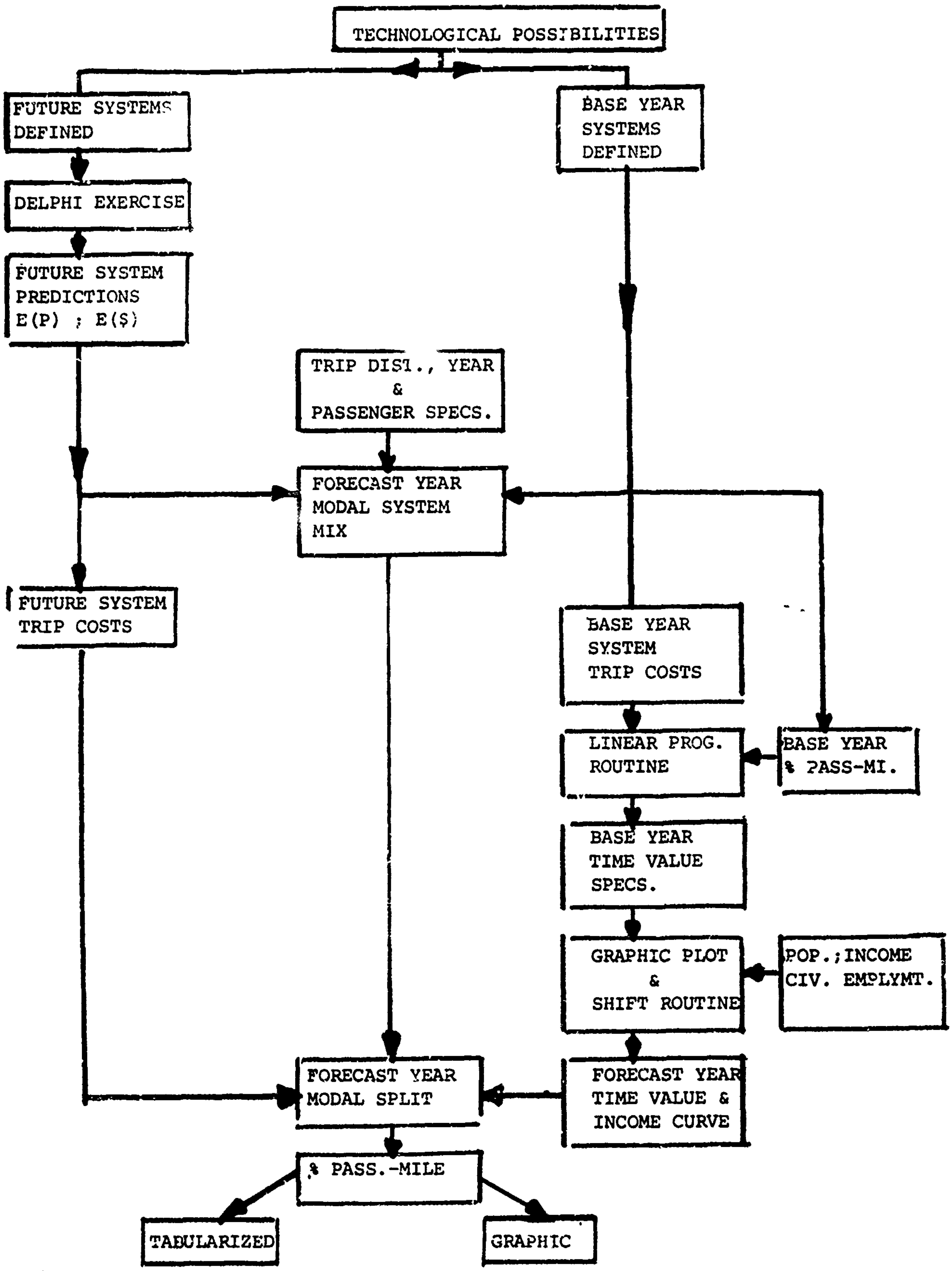
The previous paragraphs described the Delphi exercise and the use of its output. The purpose of the following paragraphs is to provide a description of a methodology that makes further use of the Delphi output as well as a modified time value concept modal split model, initially developed by NASA*, and produces an aggregate modal split of transportation as a function of trip distance, out-of-pocket costs and time value. Figure K is a flow diagram of the methodology.

The Delphi output becomes the basis for establishing a mix of systems to offer as alternatives for a modal choice. The modified version of the NASA model is the mechanism used to predict how many travelers might choose one mode over another.

---

*Drake, H.M.; Kenyon, G.C.; and Galloway T.L., Time-Value Analysis of Civil Passenger Transportation Short Haul, 1967, 1975 (Working Paper), July 15, 1968 and Future Short Haul Air Transportation (Working Paper) December 17, 1969, NASA OART, Mission Analysis Division, Moffett Field, California.

Figure K: AGGREGATE MODAL SPLIT MODEL FLOW DIAGRAM



Subsequently, the time series summation and display at a given trip distance of such choice behavior becomes a technological forecast of how new systems might be used in a competitive market. The changing of values of equation parameters (such as velocity, cost/mile, interface time and etc.) permits a sensitivity analysis and indication of the systems and capabilities that technological improvements might be focused on to improve a system's performances & consequently attract more users.

4.3.2 NASA Model

The NASA model is designed to account basically for the cost of each trip as a round trip, "portal-to-portal". Therefore, each trip is made of two paths one of which is the mirror image of the other. The functional trip elements along a path are assumed to be broken into 3 factors as shown in Figure L. Consequently, each round trip consists of two major trip elements and four interfaces. The interfaces include all the local transportation costs, delay times, and mode used to get a traveler to the initiation of the major trip element. In effect, Tbl.1-1 represents all the possible modes (systems) that could be used for a major trip element (round trip).

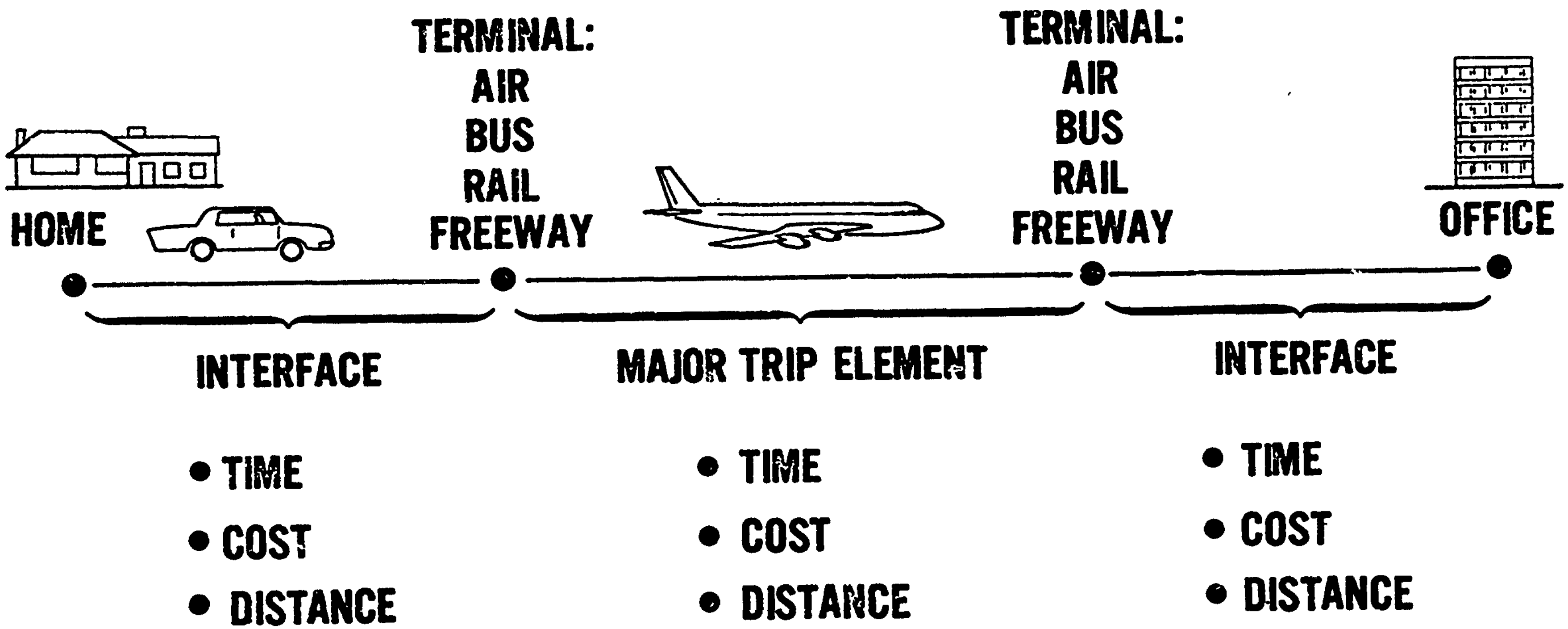


FIGURE L: AN EXAMPLE OF ONE WAY TRIP ELEMENTS

The NASA model calculates and stores all of the costs generated as a result of using a particular mode over the major trip element of Figure L. A typical printout of this information for one mode (i.e., the automobile) is shown in Figure R. The number and various types of inputs that are used in generating such costs are identified in Appendix 4.

The model has the additional feature of examining, as a function of increasing time values and trip distances, the cost of using each available mdoe and identifying that mode which is least expensive to make the trip. This identification process assumes that people select that mode and only that mode which has the minimum cost. As one final output, the model maps out as a function of trip distance and time value (T.V.) the minimum cost modes (Figure M).

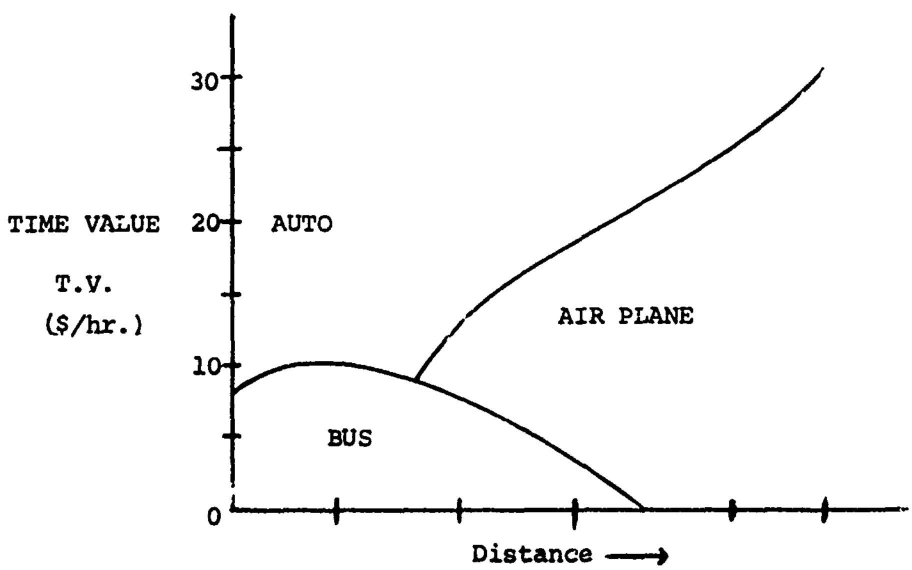


FIGURE M: MODAL SPLIT - TIME VALUE MAP AS A FUNCTION OF MINIMUM COST

For instance, Figure M indicates that everyone with a time value of less than $5.00/hr. will choose to travel by bus because that mode has the least cost when a T.V. of $5.00 or less is used as one of the indexing parameters to calculate the total cost. Furthermore, if two modes were available for use, one costing $3.75 and the other $3.70, the model would select only that mode costing $3.70 as a modal choice, eliminating from consideration the slightly more expensive mode. The methodology and modification discussed in paragraph 4.3 eliminates this type of logic.

In addition, even on an aggregated basis, the NASA model had no constraint with respect to demand or capacity. The modification also has included the capability to handle this.

4.3.3 Methodology Assumptions

The methodology uses as its basic calculating framework the NASA Model. However, certain modifications have been made to improve its forecasting capability. These modifications require certain assumptions with respect to choice behavior system availability and demand. These are:

Choice Behavior

- People associate a cost to the amount of time used while traveling between an origin and destination. This cost per unit of time is defined as a time value. It is generated in addition to out-of-pocket expenses.

- An individual's time value is not constant, it varies as a function of trip purpose and trip length. At any trip length, there exists a distribution for the number of passenger milos accrued as a function of a range of time values.

- At minimal time values, mode selection is inversely proportional to total trip cost; that is, the system with the least cost will attract the most riders.

- At midrange time values, mode selection is inversely proportional to total trip cost plus such factors as comfort, velocity and convenience as perceived by each individual traveler. These factors can be lumped and expressed as a single weighting factor which influences the preference of one mode over another. These weighting factors are directly proportional to the observed distribution of passenger-miles per mode.*

- At the maximum range of time values, mode selection is inversely proportional both to total trip cost and the total trip time squared to complete the trip.

---

*See Appendix 4 which contains a breakdown of Table 1-1, groups of 1, 2, 3, 4 or more passengers per mode per trip length for 1965. This breakdown is identified as Tables 1-1A.

- Time value distributions have the same trend change over time as do income distributions. As a percentage of the population shifts in time to a higher income rate, a similar percentage shift occurs for the percentage of passenger miles accrued at a specific time value.*

System Availability

- Each system is available wherever required and to the extent required.

- There is enough demand to match the system's capacity to attract passengers. Limitation can be set, however, at any capacity level.

4.3.4 Modal Split Methodology

The methodology depends on several sequential steps. They are:

Step 1: Select a year for forecasting the modal split of passenger miles. Call this the forecast year.

Step 2: Select the mix of systems that are expected to be available for use in the forecast year. Use a Delphi Technique to assist in estimating the availability of new systems.

Step 3: Select a size of a passenger group (1, 2, 3, 4 or more) and an average trip distance within each trip interval of Chart 3, and determine a 1965 Passenger Mile - Time Value Distribution curve. (Technique discussed in paragraph 4.3.5.)

---

*See paragraph 4.3.6 & Figure 0 for percent shift manipulation technique.

Use the modes available in 1965 and their percentages of passenger-miles, as defined in Tbl.1-1a, as input data to determine the 1965 Passenger Mile - Time Value Curve.

Step 4: Plot both a 1965 Population - Income distribution and the forecast year Population - Income distribution curves.

Step 5: Adjust the 1965 Passenger Mile - Time Value distribution curve of Step 3 to reflect a percent shift of passenger miles accrued corresponding to the percent shift income for the population from 1965 to the forecast year.

Step 6: Develop complete "portal-to-portal" input parameters for all systems to be used in the modal split. (Example set of input parameters are tabularized in Appendix 4.)

Step 7: Run the modified NASA Modal Split Model and determine the percent passenger miles that are estimated to be attracted to each mode. Plot the results as shown in Figure AA-1 through Figure GG-2.

Step 8: Repeat Steps 1-7 as necessary to develop outputs as the size of groups * vary, forecast year changes, capacity of modes are limited, or any other system parameters such as cost/mile, velocity, interface time etc., are allowed to change. This produces data for sensitivity and comparative analyses.

---

*In the NASA Model both the size of the group and the number of members within the group who have a time value can be defined (e.g. group size is 4; only 2 have a time value, the remaining members do not).

4.3.5 Derivation of the Base Year Passenger Mile - Time Value Curve

One starts with the assumption that at a specified distance a Passenger Mile - Time Value distribution for the base year exists. The problem is to describe and calibrate this curve in terms of the passenger mile data that has been documented for 1965. It is accomplished by using Ohms law,* (Direct Current Theory) and Linear Programming techniques. Figure N is an assumed cumulative Passenger Mile - Time Value plot. On this plot time values range from 0 to $20/hour. Three time values, along the abscissa, corresponding to a minimal (T.V.) midrange (TV_2) and maximum time value (TV_3) are marked. They are at $0/hr., $10/hr. and $20/hr respectively. Corresponding to these points, 3 intervals along the passenger mile ordinate are also marked. They are identified as K_1, K_2, and K_3 and the sum of their values always adds up to 100%. Consequently, if one can determine the values of K's corresponding to predetermined values of T.V., a piece-wise linear** approximation to the Passenger Mile - Time Value distribution curve can be constructed. The following application of Direct Current (DC Theory and Linear Programming provides a means for solving K values.

---

* Ohms Law: E = IR i.e., the voltage drop E, measured in volts,,across a resistance is equal to the product of the current I, measured in amperes, flowing through the resistance times the size of the resistance R measured in ohms.

**With the data available,Tbl.1-1 , a piece-wise linear curve gave the best and most consistent curve fit Other polynomial curve fits produced undesirable and unreasonable peturbations at the higher T.V. values.

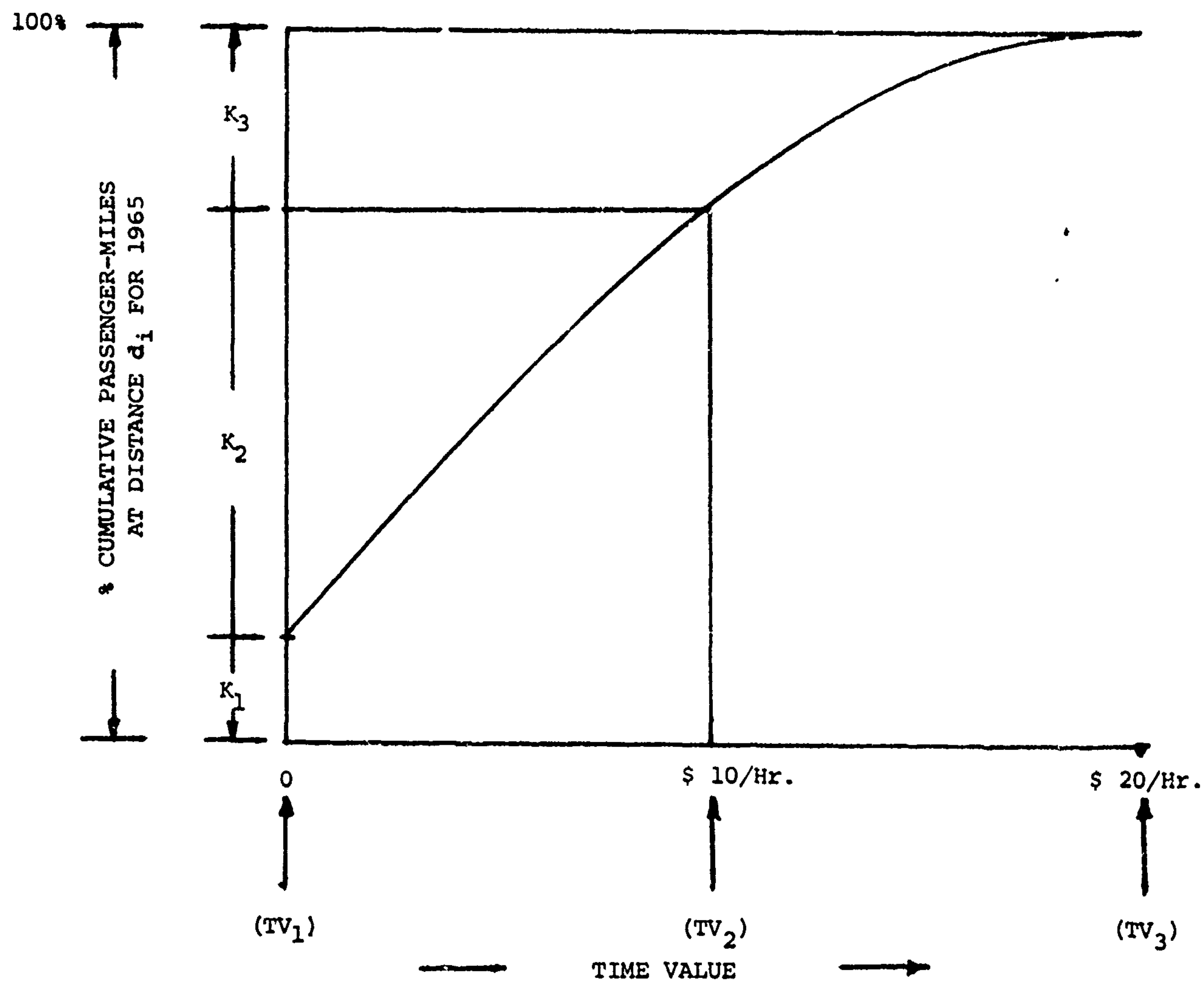


FIGURE N ASSUMED CUMULATIVE PASSENGER-MILE VS. TIME VALUE DISTRIBUTION CURVE

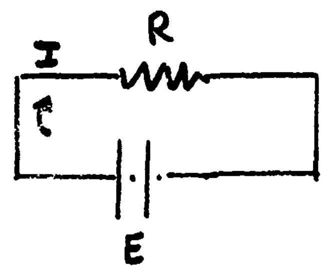
Each K value defines the total number of passenger miles that "flow" as a result of trips being made on available modes of transportation. The modes in turn are considered as a set of parallel transportation paths between an origin and destination.

An analogy can be drawn between the flow of current through parallel resistors in a d.c.-circuit and the number of passengers that use one transportation mode over another, when several such possibilities exist. In fact, this electrical analogy can be refined further in the sense that total costs for a trip act as an impedance to the use of a mode similar to the resistance of an electrical circuit acting as an impedance to the flow of current. If instead of the number of passengers, passenger-miles are considered to be the "flow" than the algebraic relationship used to determine current flow in d.c.-circuit theory can be used to account for passenger mile flow.

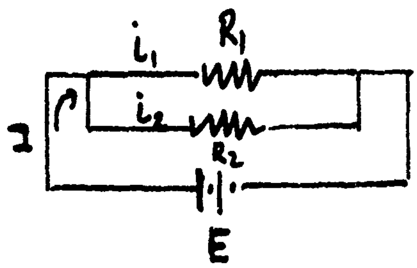
Consider the following:

<u>SERIES CIRCUIT</u>

Let: I = Total Circuit Current Flow
R = Circuit Resistance
E = Voltage Drop Across R



PARALLEL CIRCUIT



$I = i_1 + i_2$

R_1 = Branch Resistance

R_2 = Branch Resistance

E = Voltage drop across each resistor

The parallel circuit can be drawn as a series circuit by solving for a circuit equivalent Resistance, R_{EQ}, which will draw the same total circuit current, I.

Solving R_{EQ}:

Case I: Two Resistors in Parallel

$$R_{EQ} = \frac{R_1R_2}{R_1+ R_2}$$

Case II: Three Resistors in Parallel

$$R_{EQ} = \frac{R_1R_2R_3}{R_1R_2+ R_1R_2+ R_2R_3}$$

Case III: Four Resistors in Parallel

$$R_{EQ} = \frac{R_1R_2R_3R_4}{R_1R_2R_3+ R_2R_3R_4+ R_3R_4R_1+ R_4R_1R_2}$$

(The formula for the value of R_{EQ} for any number of resistors in parallel can be induced from the above pattern of formula derivation.)

Since the total current through a parallel circuit can be defined as

$$I = \sum_{i=1}^{N} i_i \qquad N = \text{number of resistors}$$

and

$$i_i = \frac{R_{EQ}}{R_i} \cdot I$$

Now to transform the equations developed for an electrical theory into ones applicable to transportation let:

$\$_i$ = Total cost of transportation/mode i $i=1,2,3,\ldots,M$

$\$_{EQ}$ = Hypothetical equivalent total cost when more than one transportation mode exists, derived like R_{EQ} for D.C. circuits.

K_j = Percent passenger miles between the j-1 and jth T.V. (See Figure N).

n_i = Percent passenger-miles attributed to the ith transportation mode $i=1,2,3,\ldots,M$

and $\sum_{i=1}^{M} n_i = K_j \quad ; \quad \sum_{j=1}^{N} K_j = 100\%$

Then by substitution, according to the analogy between electrical circuit theory and transportation cited earlier,

$$n_i = \frac{\$_{EQ}}{\$_i} \cdot K_j \qquad j=1,2,3,\ldots,N$$

Since the NASA modal split model is able to calculate for any mode as function of trip distance the round trip cost, a means for calculating $\$_i$ is readily available. While the original NASA modal split model had only a few increments of trip length, the modified model is able to handle many increments of trip length within each category of trip distance identified on Tbl.1-1 and 1-1a. Moreover, the original model used air distance as the basis for the accounting of trip distances. The modified model still does this but appropriate ratio factors are used

to adjust a trip distar : to account for the expected differential between an air distance and a modal surface distance. (See system input parameters, Appendix 4). Finally, at any given trip distance, the value of time (T.V.) is used simultaneously as both an indexing and augmenting variable. This is done in order to track and to calculate the change in total trip cost/mode as T.V. ranges from \$0/hr. to \$20/hr. Given the preceding information, the following set of linear inequations and equations can be derived:

$$\sum_{j}^{3} \left(\frac{\$EQ}{\$_{ij}} \alpha_{ij} \right) K_j \leq C_i$$

where: i=1,2,3,...,M and M corresponds to the number of available base year transportation modes, and

$$\sum_{j=1}^{3} K_j = 1 \; ; \; 0 \leq K \leq 1$$

$0 \leq C_i \leq 1$ and C_i represents the cumulative percentage of passenger miles for mode i*.

The $\alpha_{ij's}$** are weighting factors and they are defined as follows:

At the minimal time value: $\alpha_{i1} = 1$

At the midrange time value: $\alpha_{i2} = f(C_1, C_2, C_3)$

At the maximum range time value: $\alpha_{i3} = f(t_i^2)$

where t_i = mode i total trip time.

---

* Tbl. 1-1 & 1-1A show the percentage of passenger miles for each base year mode in any one of 11 distance intervals. It is assumed that once defined, the relationship between $C_{i's}$ remains the same for any trip distance within a specified trip distance interval.

** The α_{ij} relationshipsrequired are discussed in detail in subsequent paragraphs.

By allowing $\alpha_{ij}=1$ at the minimal time value, the cost of a trip becomes the only weighting factor. It is assumed that at the lowest time value, people probably make their decision, for the most part, on the basis of the least cost mode.

By allowing $\alpha_{ij}=f(C_1, C_2, C_3)$ at the midrange time value, the cost of a trip is not the only factor which affects the modal split. Each mode's cost ratio, $\frac{\$EQ}{\$_{ij}}$, is modified to reflect an influence from the distribution profile that was documented as occuring in the base year.

By allowing the $\alpha_{ij}=f(t_i{}^2)$ at the maximum time value, the cost of a trip is again not the only weighting factor. Each mode's cost ratio is modified to reflect the assumption that at high time values, people probably base their transportation choice (in a non-linear fashion) more on the amount of time a trip will take than on its total cost, choosing first that mode which will complete the trip most quickly.

Finally, the set of inequations cited earlier, can be constituted as a linear programming (L.P.) minimumization constraint problem. Considering only 3 base year modes of transportation, the mathematical structure of the L.P. problem can be described as follows:

*Objective Function: $\text{MIN} \sum_{j=1}^{8} S_j$ where S_j = artifical or slack variables

Subject To:

$$\sum_{j=1}^{3} K_j = 1 \; ; \; 0 \leq K_j \leq 1$$

$$\sum_{j=1}^{3} \frac{\$_{EQ}}{\$_{ij}} \alpha_{ij} \quad K_j \leq C_i \qquad i=1,2,3,\ldots,M$$

And the last inequation can be expanded as follows:

$$(2) \qquad \frac{\$_{EQ}}{\$_{11}} \alpha_{11} \quad K_1 + \frac{\$_{EQ}}{\$12} \alpha_{12} \quad K_2 + \frac{\$_{EQ}}{\$_{13}} \alpha_{13} \quad K_3 \leq C_1$$

$$\frac{\$_{EQ}}{\$_{21}} \alpha_{21} \quad K_1 + \frac{\$_{EQ}}{\$_{22}} \alpha_{22} \quad K_2 + \frac{\$_{EQ}}{\$_{23}} \alpha_{23} \quad K_3 \leq C_2$$

$$\frac{\$_{EQ}}{\$_{31}} \alpha_{31} \quad K_1 + \frac{\$_{EQ}}{\$32} \alpha_{32} \quad K_2 + \frac{\$_{EQ}}{\$_{33}} \alpha_{33} \quad K_3 \leq C_3$$

Because of the modal split concept, the coefficients of any K_j must be considered as components of a column probability vector and must sum to one. For instance for $K_j = K_2$

$$\left(\frac{\$_{EQ}}{\$_{12}}\right)\alpha_{12} + \left(\frac{\$_{EQ}}{\$_{22}}\right)\alpha_{22} + \left(\frac{\$_{EQ}}{\$_{23}}\right)\alpha_{23} = 1 \quad \text{(EQUA. 1)}$$

This assists in the solution of α_{ij}'s at midrange and maximum time values, TV_2 and TV_3 respectively, as follows:

---

*If one had perfect data the set of inequations (2) could be written as a set of equations. To permit this under the present data conditions, slack and artifical variables (S_j's) are introduced. The objective function minimizes the use of such variables and forces the selection of the best set of K_j's with the data available and the formulations hypothesized. In effect the objective function does two things. It minimizes the percent of error between observed data and construction assumptions. It indicates (by its value) which set of inequations in any computer run has the most error, and consequently where additional factors to explain better passenger behavior are required. Errors occur primarily where the C_i's are more evenly distributed, i.e., at the larger distance intervals for passenger group size = 1.

At Midrange, TV_2, the $C_{i's}$ have to be ordered with respect to their value.

Given: $C_1 > C_2$; $C_1 > C_3$

Then:

$$\frac{\alpha_{22}}{\alpha_{12}} = \frac{C_2}{C_1} \quad \text{and} \quad \frac{\alpha_{32}}{\alpha_{12}} = \frac{C_3}{C_1}$$

$$\alpha_{22} = \alpha_{12}\left(\frac{C_2}{C_1}\right) \qquad \alpha_{32} = \alpha_{12}\left(\frac{C_3}{C_1}\right)$$

AND by substitution into (EQUA. 1)

$$\alpha_{12}\left(\frac{\$_{EQ}}{\$_{12}}\right) + \alpha_{12}\left(\frac{\$_{EQ}}{\$_{22}} \cdot \frac{C_2}{C_1}\right) + \alpha_{12}\left(\frac{\$_{EQ}}{\$_{32}} \cdot \frac{C_3}{C_1}\right) = 1$$

$$\alpha_{12} = \frac{1}{\$_{EQ} \cdot \left[\frac{1}{\$_{12}} + \frac{1}{\$_{22}}\,\frac{C_2}{C_1} + \frac{1}{\$_{32}} \cdot \frac{C_3}{C_1}\right]}$$

$$\alpha_{12} = \frac{\$_{12}\ \$_{22}\ \$_{32}\ C_1}{\$_{EQ}\left[\$_{22}\ \$_{32}\ C_1 + \$_{12}\ \$_{32}\ C_2 + \$_{12}\ \$_{22}\ C_3\right]}$$

Likewise, for $K_j = K_3$ at the maximum time value range, TV_3, the following can be determined:

Given $t_1 < t_2$; $t_1 < t_3$

$$\frac{\alpha_{23}}{\alpha_{13}} = \left(\frac{t_1}{t_2}\right)^2 \quad \text{and} \quad \frac{\alpha_{33}}{\alpha_{13}} = \left(\frac{t_1}{t_3}\right)^2$$

$$\therefore\ \alpha_{23} = \alpha_{13}\left(\frac{t_1}{t_2}\right)^2 \qquad \therefore\ \alpha_{33} = \alpha_{13}\left(\frac{t_1}{t_3}\right)^2$$

Again, since the coefficient of K_3 must also sum to 1 and (EQUA. 1) we formulated as follows:

$$\alpha_{13}\left(\frac{\$_{EQ}}{\$_{13}}\right) + \alpha_{13}\left(\left(\frac{\$_{EQ}}{\$_{23}}\right)\left(\frac{t_1}{t_2}\right)^2\right) + \alpha_{13}\left(\left(\frac{\$_{EQ}}{\$_{33}}\right)\left(\frac{t_1}{t_3}\right)^2\right) = 1$$

$$\alpha_{13} = \frac{1}{\$_{EQ}\left[\frac{1}{\$_{13}} + \frac{1}{\$_{23}}\left(\frac{t_1}{t_2}\right)^2 + \frac{1}{\$_{33}}\left(\frac{t_1}{t_3}\right)^2\right]}$$

$$\alpha_{13} = \frac{\$_{13}\ \$_{23}\ \$_{33}\left(t_2 \cdot t_3\right)^2}{\$_{EQ}\left[\$_{23}\ \$_{33}\left(t_2 \cdot t_3\right)^2 + \$_{13}\ \$_{33}\left(t_1 \cdot t_2\right)^2 + \$_{13}\ \$_{23}\left(t_1 \cdot t_2\right)^2\right]}$$

In subsequent paragraphs covering the discussion of the model's ability to produce modal splits, the additional use of α_{ij}'s to provide in some measure for either the affects of comfort, reliability, etc., or the introduction of a new system are touched upon.

4.3.6 Forecast Year - Time Value Curve

The preceding paragraphs described the procedures for structuring the Base Year Time Value curve, however, since projections can be made of the shift in population as a function of income and forecast year, a similar shift of the Time Value Base Year Curve to a Forecast Year Curve was considered necessary.

Appendix 1 indicates the derivation of a population vs. income curve, projections of the same to a specified forecast year, passenger miles as a function of distance and the relationship between cumulative passenger miles and cumulative population. In order to develop the relationship that mathematically exists between the Cumulative Percent Passenger Mile - Time Value distribution and the Cumulative Percent Population-Income distribution, both curves for any given trip distance and year are mapped against the same range of coordinate values. As a result, a spatial-mathematical relationship between the two curves is established. The effect of a change to one curve can easily be transferred to a corresponding effect of a change to the other. For instance, if a significant percent of the population shifts their income level as time progresses, then a similar percent shift would probably occur between cumulative percent of passenger miles and time value. Since both distributions are plotted against the same coordinates, the shift becomes one of holding the established mapping relationships intact, by assuming a 1 to 1 mapping procedure.

This can be clarified by an actual example. Consider Figure O. On this figure are plotted, with solid lines, the Cumulative Percent of Population vs. Income for the Base Year (1965) and for projected income for the Forecast Year (1975) and the Cumulative percent of Passenger Miles vs. Time Value for the Base Year. Also on Figure O there is a dotted curve representative of the Forecast Year Passenger Mile - Time Value Curve.

Given the data to plot the 3 solid line curves, an arbitrary point is identified on the 1965 Income Base Year curve corresponding to a cumulative percent of the population (e.g. pt.B corresponds to 50% of the population with an income of at most $10/hr.). Two lines are drawn through the point, one parallel to the ordinate and one parallel to the abscissa.

The concept for this construction is based on the logic that the vertical line through pt.B will intersect the projected income curve at a point (pt.5). Corresponding to a new cumulative percent of the population that will have at most the same income in the forecast year as was held by the population at pt.B in the Base year. Consequently, the line segment B 5 identifies the percentage of population that will change, i.e., shift income level.

The horizontal line through pt.B will intersect the projected income curve at a point (pt.C) corresponding to the new income rate that the population, identified by pt.B, will have by the forecast year.

Since a 1 to 1 mapping has been assumed between per cent of total passenger miles and per cent of total population, the shift just described is used as a basis for

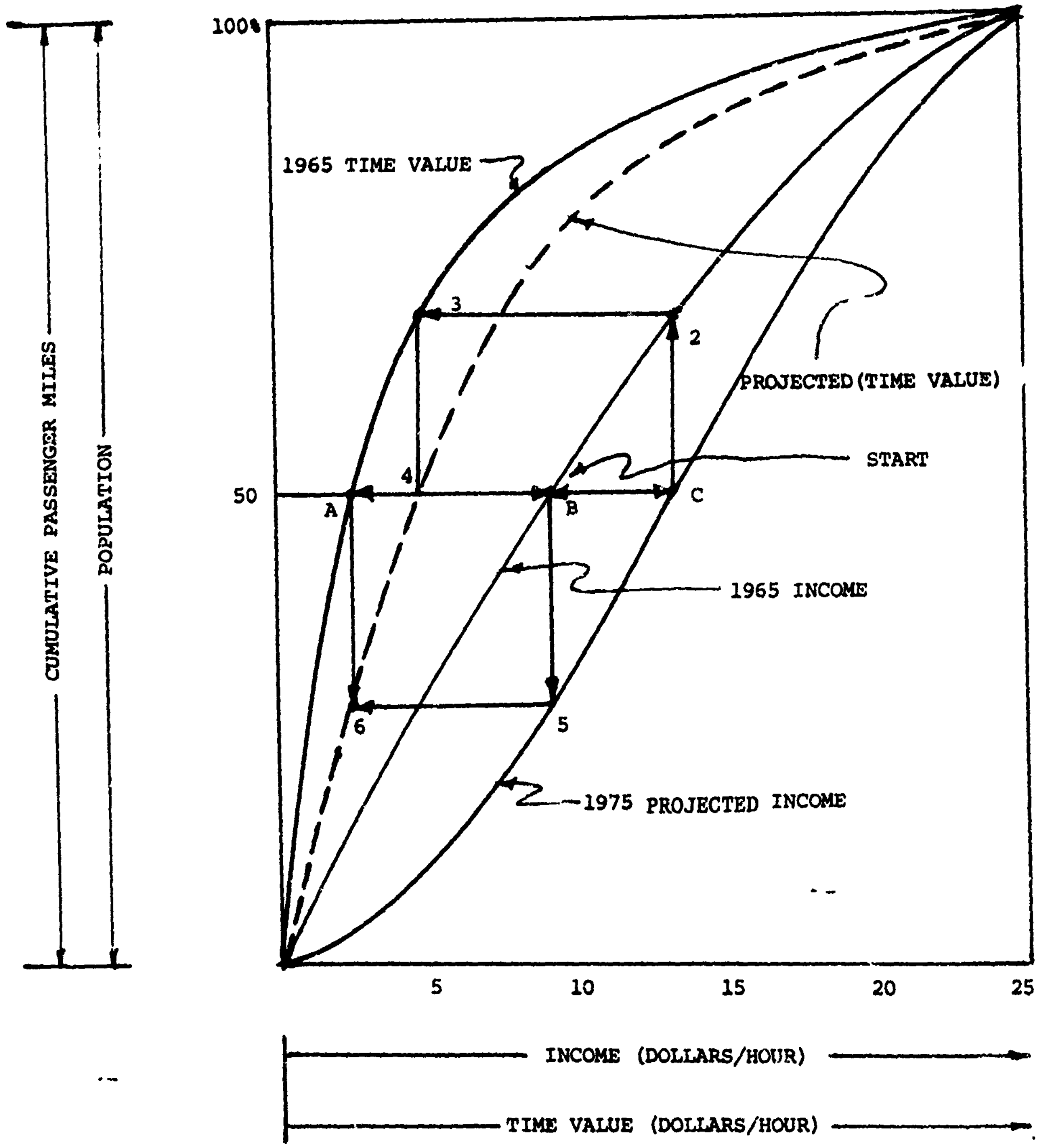


FIGURE 0: PERCENT CUMULATIVE POPULATION VS. INCOME AND PERCENT CUMULATIVE PASSENGER MILES VS. TIME VALUE

developing the projected Time Value Curve. It is done by constructing a parallelogram between the appropriate set of curves.

Again examine Figure 0. The line A6 is parallel to the line B5. Point 6 identifies the cumulative percent of passenger miles that were accrued by people with at most the same time value in the forecast year as in the base year. Likewise, developing a parallelogram from point C, one can determine the value of cumulative population in the base year that would correspond with an income level predicted for the forecast year. This value is defined at pt.2. Again, because of the 1 to 1 mapping assumption, pt.2 in effect identifies both the percent level of cumulative population and the percent level of cumulative passenger miles (pt.3) that would have had to occur. Completing the parallelogram determines pt.4 which in turn identifies the at most time value of passengers who could have accrued the passenger miles noted in the forecast year.

In summary, any arbitrary point selected on a 1965 Income Curve can be used to generate two points that must be on the path of the locus of points that form the Forecast-Year Time Value

curve. Selecting several arbitrary points is sufficient to provide enough points to construct the desired Time Value curve*.

4.3.7 Modal Split For The Forecast Year - Examples

The modal split for any forecast year at any specified average distance and number of time value passengers (1,2,3, or 4) is determined by computing the scalar product of the left hand side of the inequation:

$$\sum_{i=1}^{M} \sum_{j=1}^{6} \left(\frac{\$_{EQ}}{\$_{ij}} \alpha_{ij} \right) K_j \leq C_i \quad \text{(EQUAT. 2)}$$

This is the same inequation that was used to determine the base year Passenger Mile - Time Value curve. However, it is used in reverse to predict the modal split because at any value of K_j, the coefficients associated with each K_j are in effect column coefficients that automatically divide K_j into parts directly proportional to their value. Figure P is an example of a typical program printout. Note that summing across any row produces the value C_i (cumulative percent of passenger miles attracted by the ith mode). This is accomplished by the modified model's computer program as follows:

---

*This entire operation is all part of the data processing routines and computational procedures in the modified NASA Modal Split Model.

FIGURE P: PERCENT CONTRIBUTION FOR EACH MODE AT GIVEN TIME VALUE

MODE	TIME VALUE (DOLLARS/HOUR) 0.00	4.00	8.00	12.00	16.00	20.00	PERCENT PASSENGER MILES
AUTO	.45	6.49	8.46	12.00	0.00	0.00	27.40
BUS	.82	.15	.19	.27	0.00	0.00	1.44
TAXI	.02	.07	.12	.21	0.00	0.00	.42
PAS	.18	10.73	15.57	22.98	0.00	0.00	49.46
DIAL BUS	.10	4.73	6.69	9.76	0.00	0.00	21.28
TOTAL	1.58	22.17	31.04	45.21	0.00	0.00	100.00

LEGEND

ACTUAL DATA POINTS	CURVE	DESCRIPTION
A	•••••	SALARY DISTRIBUTION FOR 1965
B	-----	PROJECTED SALARY DISTRIBUTION FOR 1980
C	•••••	TIME VALUE DISTRIBUTION FOR 1965
D	•••••	PROJECTED TIME VALUE DISTRIBUTION FOR 1980

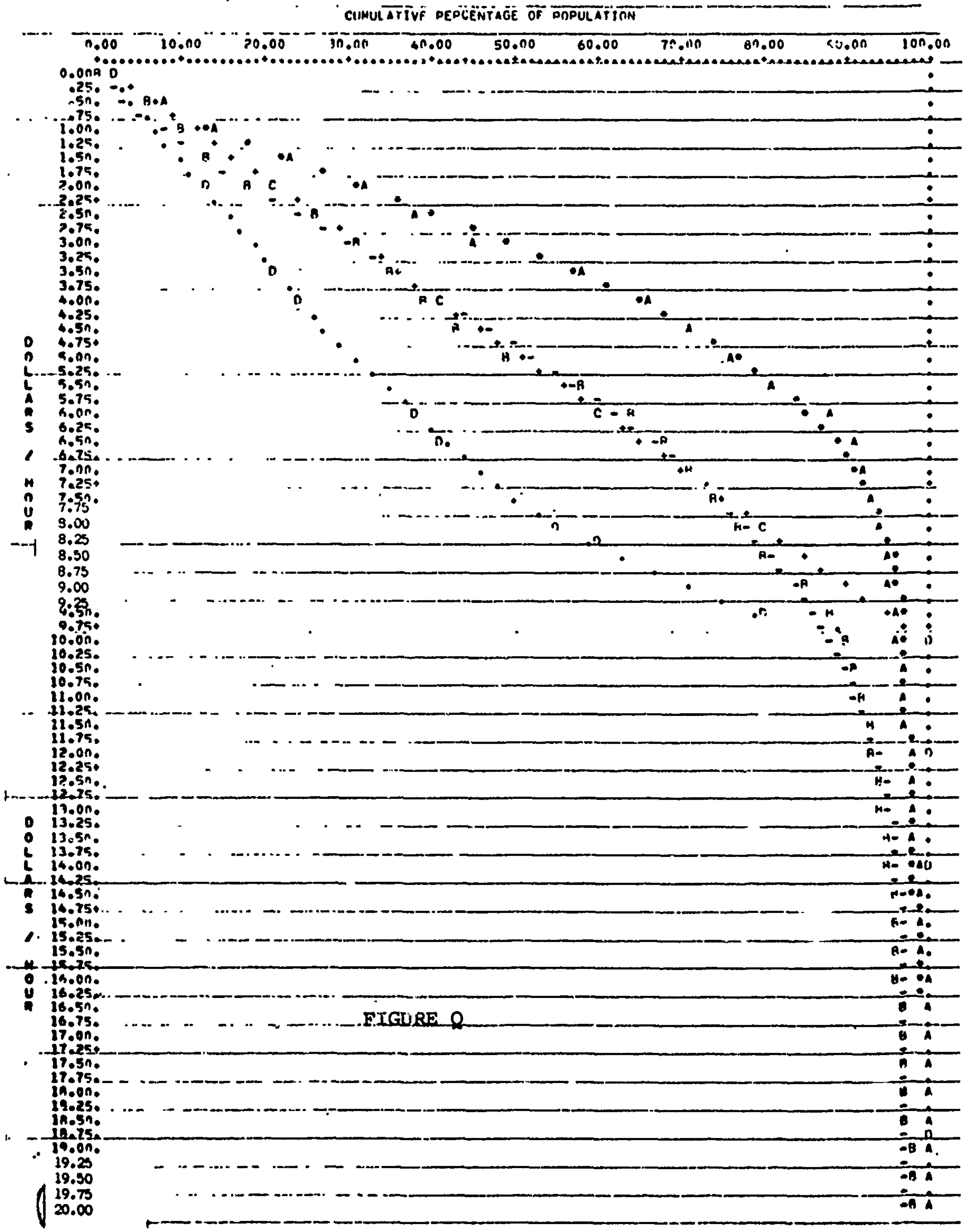


FIGURE Q

FIGURE B: ROUND TRIP

TRAVEL COST AND POTENTIAL
AUTOMOBILE

INTERCITY MODE AUTO (MIC= 1)	INTERFACE MODE (MIF= 6)
INTERCITY COST 0.00 DOLLARS + 5.50 CENTS PER MILE	ROOM RATE 8.00 DOLLARS PER DAY
COST OF COMFORT 0.00 DOLLARS PER HOUR	DESTINATION TIME 3.0 HRS.
NUMBER ED TRAVELERS 1	DESTINATION TRAVEL COST 0.00 DOLLARS
TIME VALUE TRAVELERS 1	INTERFACE TIME .30 HOURS
	INTERFACE COST 0.00 DOLLARS

ONE WAY AIR MILES	TOTAL COST DOLLARS PER HOUR 0	4	8	12	16	20	PARTIAL COST, DOLLARS INTER CITY	MEAL COST	ROOM COST	TIME, HOURS INTER CITY	TRIP TIME	TRAV TIME	GONF TIME	SPEED
0.00	0.00	1.20	2.40	3.60	4.80	6.00	0.00	0.00	0.00	0.00	.30	.30	3.30	20.00
.25	.03	1.33	2.63	3.93	5.23	6.53	.03	0.00	0.00	.02	.32	.32	3.32	20.00
.50	.05	1.45	2.85	4.25	5.65	7.05	.05	0.00	0.00	.05	.35	.35	3.35	20.00
.75	.08	1.58	3.08	4.58	6.08	7.58	.08	0.00	0.00	.07	.38	.38	3.38	20.00
1.00	.11	1.71	3.31	4.91	6.51	8.11	.11	0.00	0.00	.10	.40	.40	3.40	20.00
1.25	.14	1.84	3.54	5.24	6.94	8.64	.14	0.00	0.00	.13	.43	.43	3.42	20.00
1.50	.16	1.96	3.76	5.56	7.36	9.16	.16	0.00	0.00	.15	.45	.45	3.45	20.00
1.75	.19	2.09	3.99	5.89	7.79	9.69	.19	0.00	0.00	.17	.47	.47	3.47	20.00
2.00	.22	2.22	4.22	6.22	8.22	10.22	.22	0.00	0.00	.20	.50	.50	3.50	20.00
2.25	.25	2.35	4.45	6.55	8.65	10.75	.25	0.00	0.00	.22	.52	.52	3.52	20.00
2.50	.27	2.47	4.67	6.87	9.07	11.27	.27	0.00	0.00	.25	.55	.55	3.55	20.00

First, six increments of K_j are picked off the Forecast Year - Time Value curve. They correspond to preprogrammed time values of TV1 = \$0/hr., TV2 = \$4/hr., TV3 = \$8/hr., TV_4 = \$12/hr., TV_5 = \$16/hr., and TV_6 = \$20/hr. Figure Q is an example of curve plots the computer makes and is used to obtain the required values systems (modes).

Secondly, total costs of the systems (modes) to be compared are selected for each TV and the appropriate values of $\frac{\$_{EQ}}{\$_{ij}}$ are calculated. Figure R is an example of the computed $\$_{ij}$ for the auto.

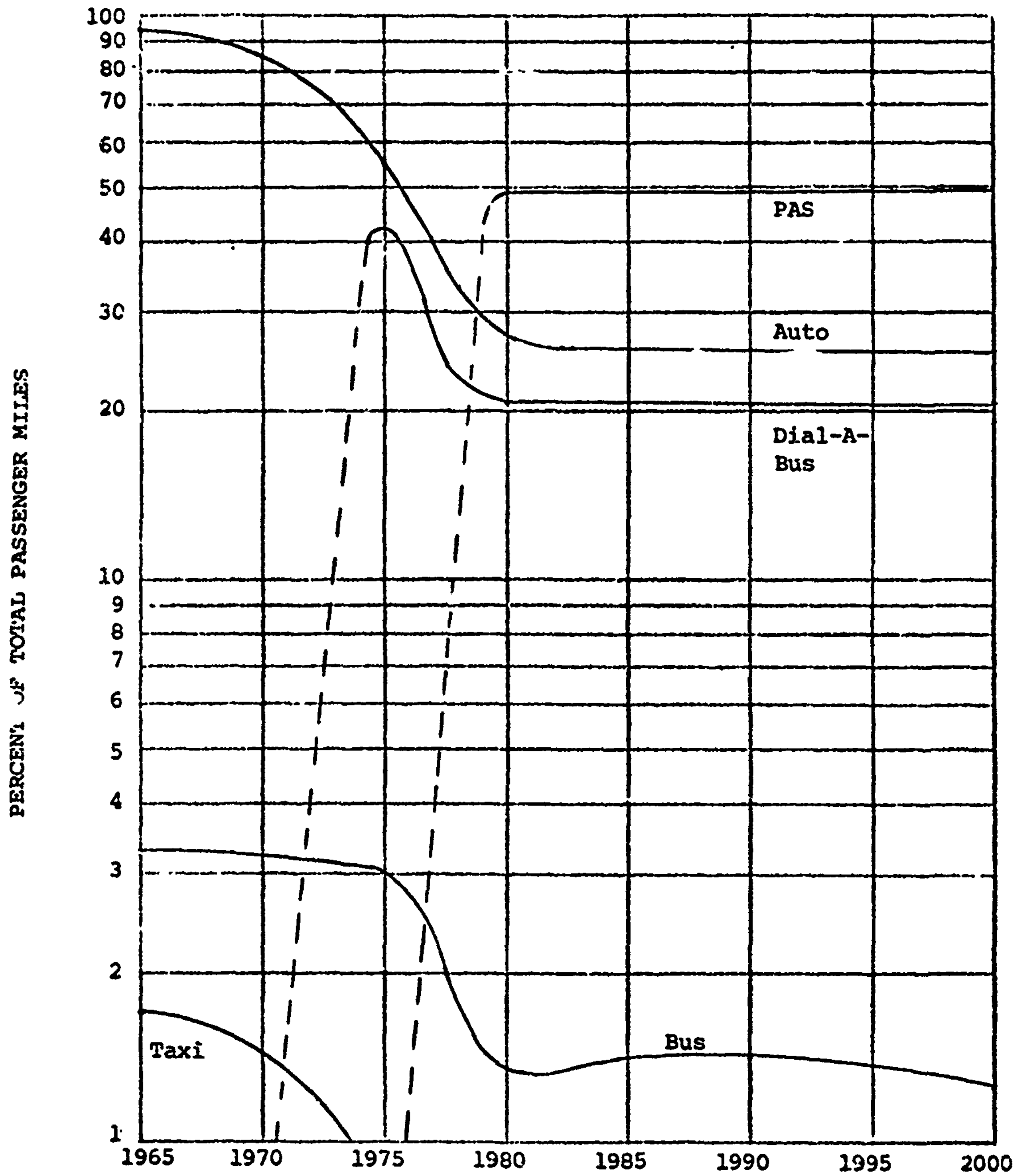
Thirdly, the correct values of α_{ij} are determined by the equations discussed in paragraph 4.3.5. New systems have been preprogrammed to assume the same α_{ij} relationship at the midrange time values (i.e., TV_1 - TV_5) as the system they are intended to compete with. However, any α_{ij} could be assigned. For instance, if a new system is designed to be competitive with both the bus and the taxi, its functional attributes such as comfort, reliability and convenience might be less than the taxi but greater than the bus. In this case, a value of α_{ij} for the new mode could be calculated as the average of the α_{ij}'s already assigned to the bus and taxi respectively. At the minimal and maximal time values, new system α_{ij}'s are determined by the same relationships that are used to determine the base year α_{ij}'s for any system.

Fourthly, the program calculates the product $\frac{\$_{EQ}}{\$_{ij}} \alpha_{ij} K_j$ for each system at every time value and stores the cumulative value of this product for all modes. At each time value a passenger-mile capacity limitation check is made for each mode. If a mode's passenger mile value exceeds the limitation, its value is set at the limit and future increments assigned to the mode are set to zero. Modal split calculations continue for the remaining eligible modes (systems) until all K calculations are made. Figure S is a typical graphical plot of the tabularized results for several forecast years of the same distance interval and the same number of passengers with equal time values.

The utility of this methodology to indicate trends and possible effects becomes apparent when one examines a span of modal split distributions. For instance, holding all input system parameters constant (Appendix 4) but varying the number of passengers in the group and the number who have time value (i.e., N=1 to N=2), the results shown in Figure AA-1 through Figure GG-2 for all 7 distance intervals of Table 1-1 and 1-1a can be observed.* Compare Figure AA-1 representing 1 passenger and Figure AA-2 representing 2 passengers. Note

*Figures AA-1 through GG-2 are arranged in pairs, that is, AA-1 is paired with AA-2; AB-1 with AB-2, AC-1 with AC-2, etc., so that comparison between 1 and 2 passengers (all with time value) can be easily reviewed.

FIGURE S: PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Other Urban

DISTANCE INTERVAL: 0 - 2.5 Miles

NO. OF PASSENGERS: 1

AVERAGE DISTANCE : 1 Mile

NO. OF PASSENGERS WITH TIME VALUE : 1

how in Figure AA-2 the automobile begins to gain a percentage of the passenger miles lost to the new systems in Figure AA-1. Also note how much more rapid the demise of the conventional bus and train is predicted in Figure AA-2 over Figure AA-1. Other effects can also be studied. For instance, the effects of changing one system parameter over another (e.g. interface time vs. velocity) or omitting development of some systems in favor of others can be observed.

As an example in the 0-2.5 miles distance interval, the block velocities of the MAC systems were raised from about 10 mph to 30 mph and their interface time increased from .03 hrs. to .20 hrs. All other systems remained the same. Even though the .20 hrs. was equivalent to the best time of any other available system (i.e., the taxi). The distribution again shifted back to the automobile. See Figure AA-1 and AA-1a. This emphasizes the importance of interface time over velocity. Analysis could be made to gain insight on design interface time vs. velocity requirements.

Finally, in the distance interval 20-50 various systems were omitted and the distribution plotted. Figure CD-1 represents the case when all available systems are available for choice.

The others had some omitted from the base as follows:

	OMITTED
Figure CD-1a	HSRA, Auto Pallet
Figure CD-1b	HSRA, TVS, Auto Pallet
Figure CD-1c	HSRC, TACV, Auto Pallet

The shift back to the automobile in all cases is observed with a slight tendency to increase the use of the light VTOL. The sample responses presented here as well as other runs prove another important fact. In spite of technological innovations, it appears that it would be very difficult to drive automobiles as we know them today off the road, without specific legislation restricting their use.

Figure Set I: AA-1 through GG-4

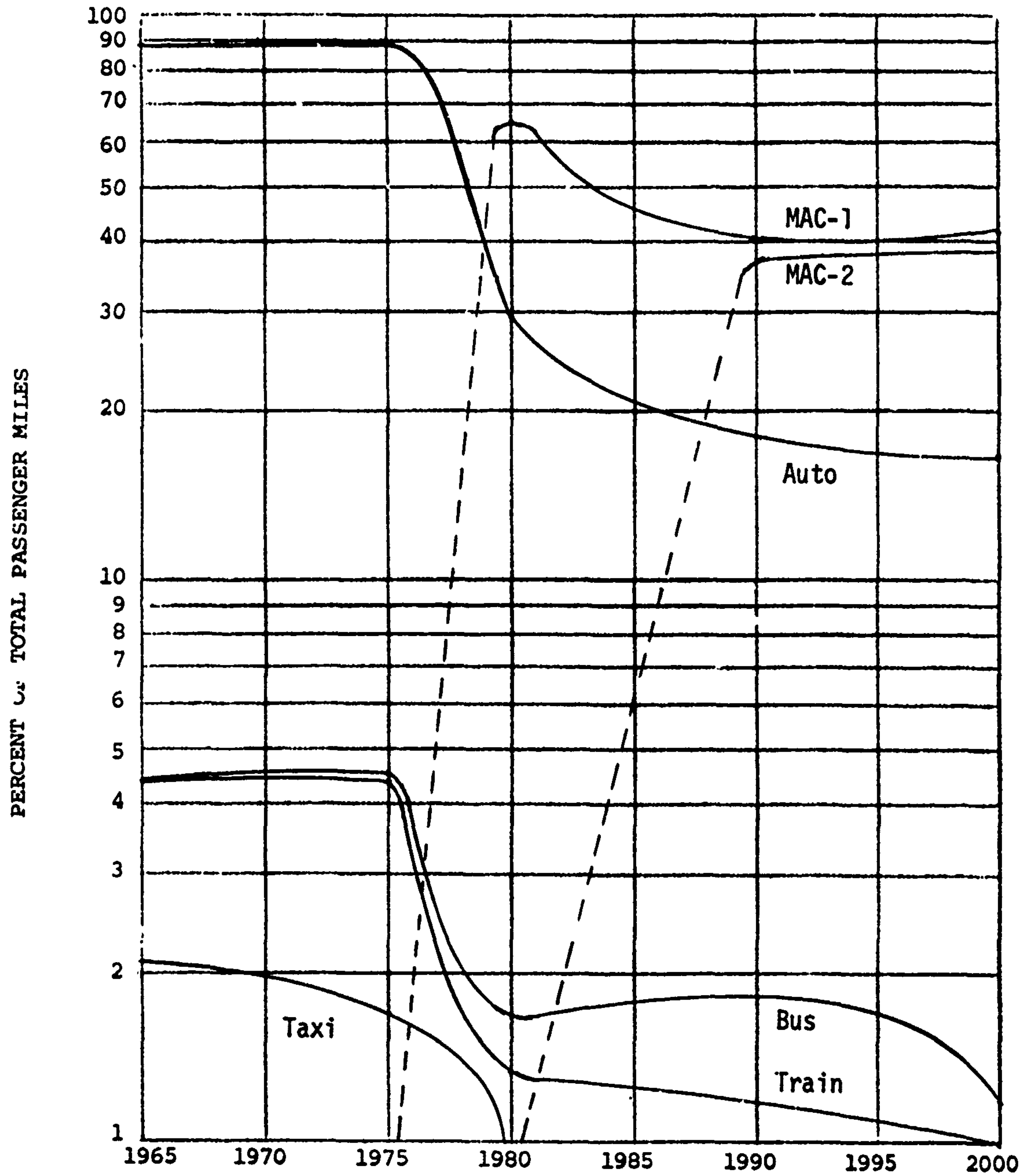
All Distance Intervals Size of
Passenger Groups: 1,2, and 4 number of
Time Value Passengers 1, 2, and 4.

NOTE:
In reviewing the attached sets of response curves, the reader is advised to be aware of the following points:

-- The graphs have been drawn on semi-logrithmic (2-cycle) paper. This permitted a clearer presentation of those systems which are predicted to capture a very small portion of the market. At the same time, as a result of the spatial relationships that are portrayed on logarithmic paper, perturbations to distributions at the lower percentages appear accentuated and small computer rounding errors could cause multi-mode distributions when in fact multi-mode distributions can not occur.

-- The dotted lines on the curves represent the gradual introduction of new systems. Since they are arbitrarily drawn, the modal split may not add to 100% over the interval while the new systems are being introduced. The modal split should, however, add to 100% at the Forecast years of 1975, 1980, 1990 and 2000.

FIGURE AA-1
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Dense Urban

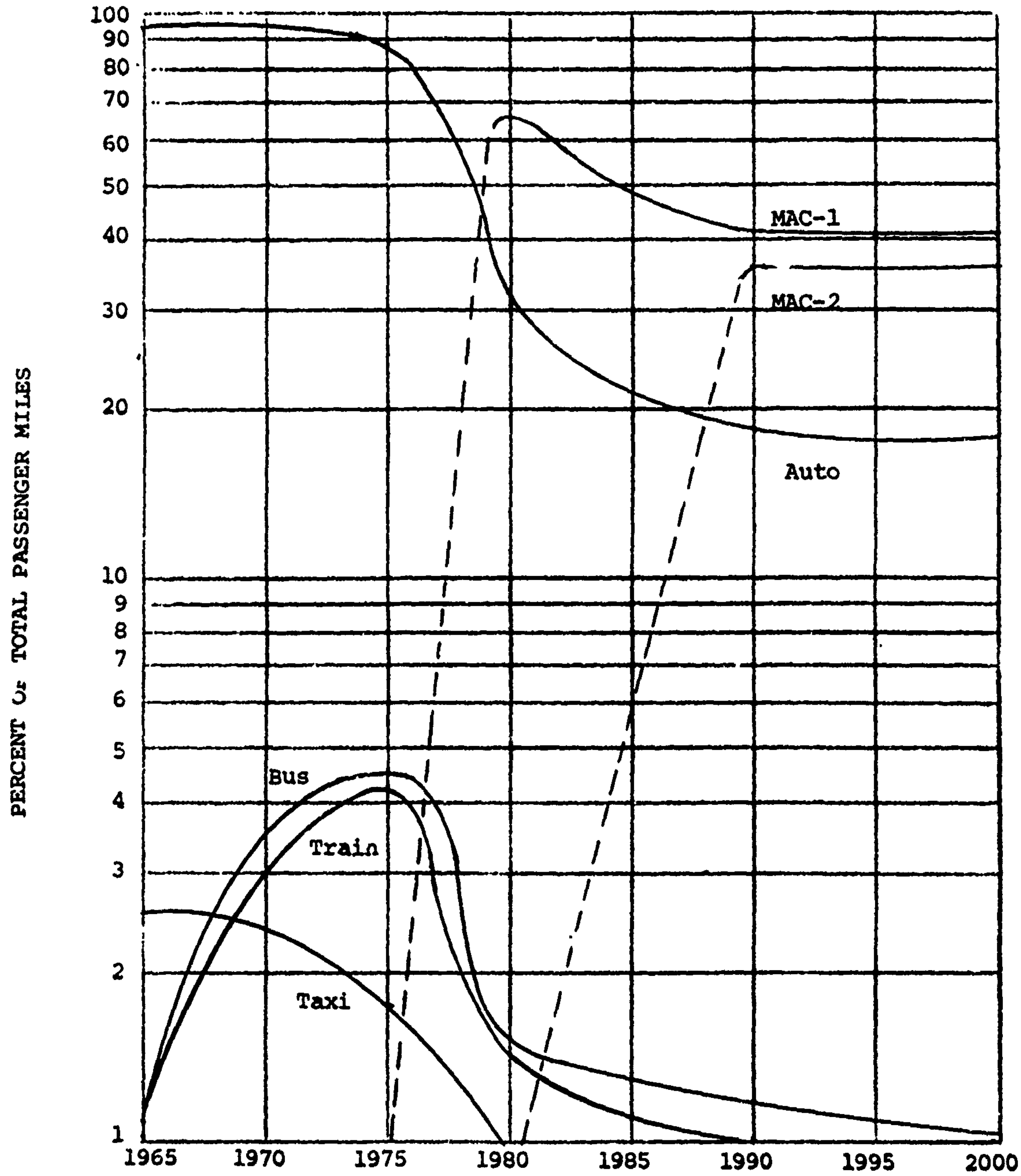
DISTANCE INTERVAL: 0-2.5 miles

NO. OF PASSENGERS: 1

AVERAGE DISTANCE : .75 miles

NO. OF PASSENGERS WITH TIME VALUE : 1

FIGURE AA-2
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Dense Urban

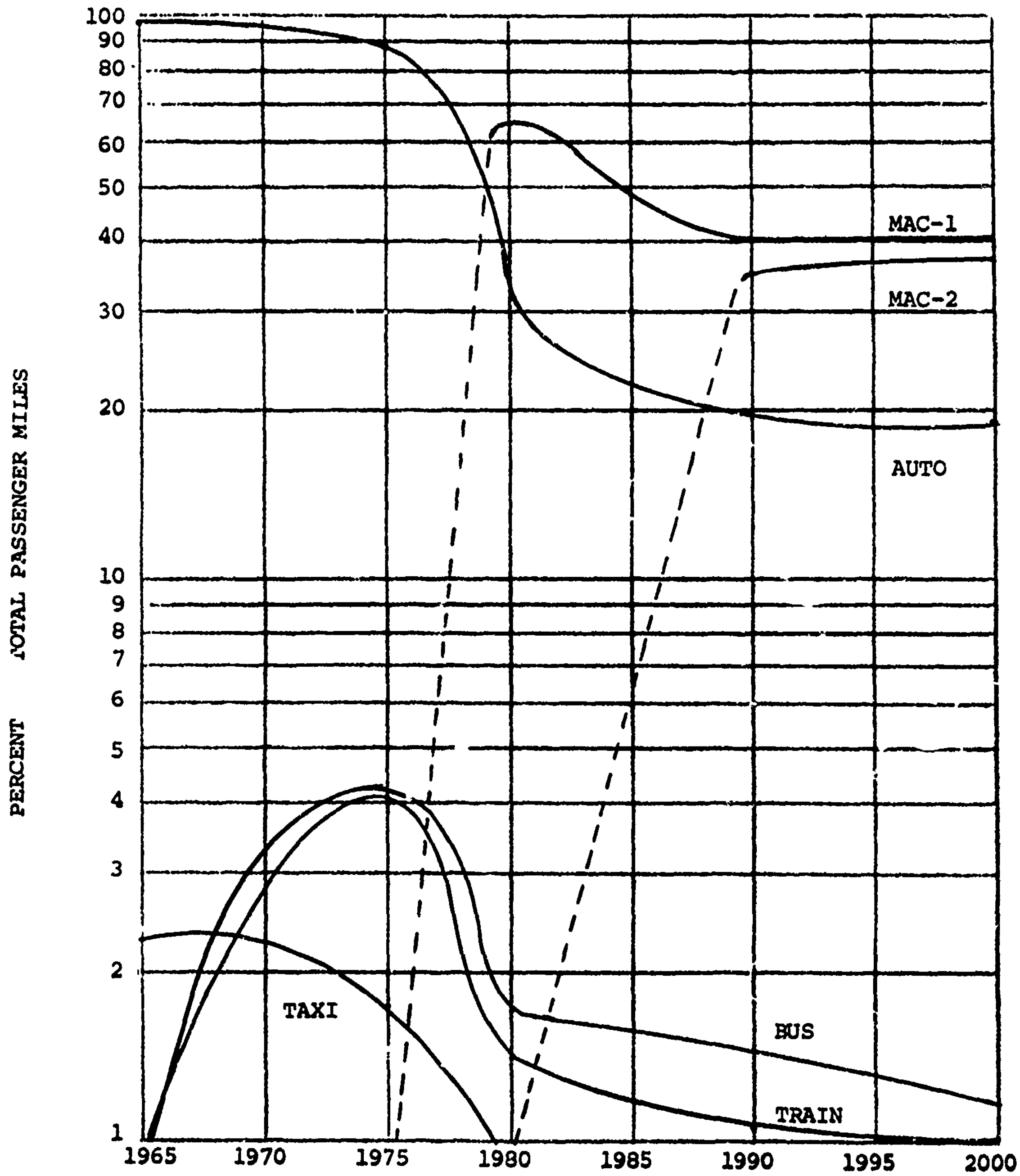
DISTANCE INTERVAL: 0-2.5 miles

NO. OF PASSENGERS: 2

AVERAGE DISTANCE : .75 miles

NO. OF PASSENGERS WITH TIME VALUE : 2

FIGURE AA-4
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Dense Urban

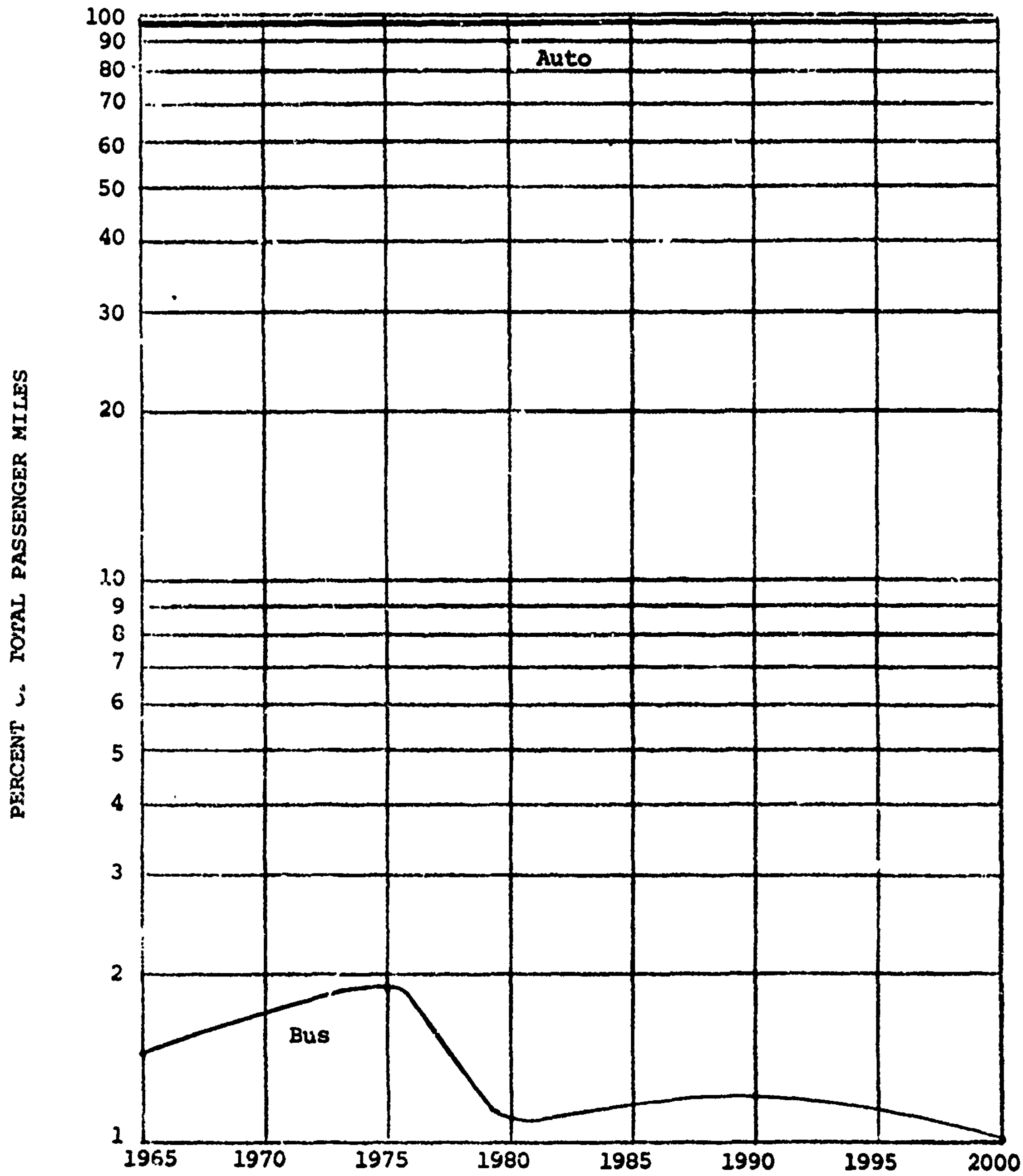
DISTANCE INTERVAL: 0-2.5 Miles

NO. OF PASSENGERS: 4

AVERAGE DISTANCE : .75 Miles

NO. OF PASSENGERS
WITH TIME VALUE : 4

FIGURE AB-1
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Non-Urban

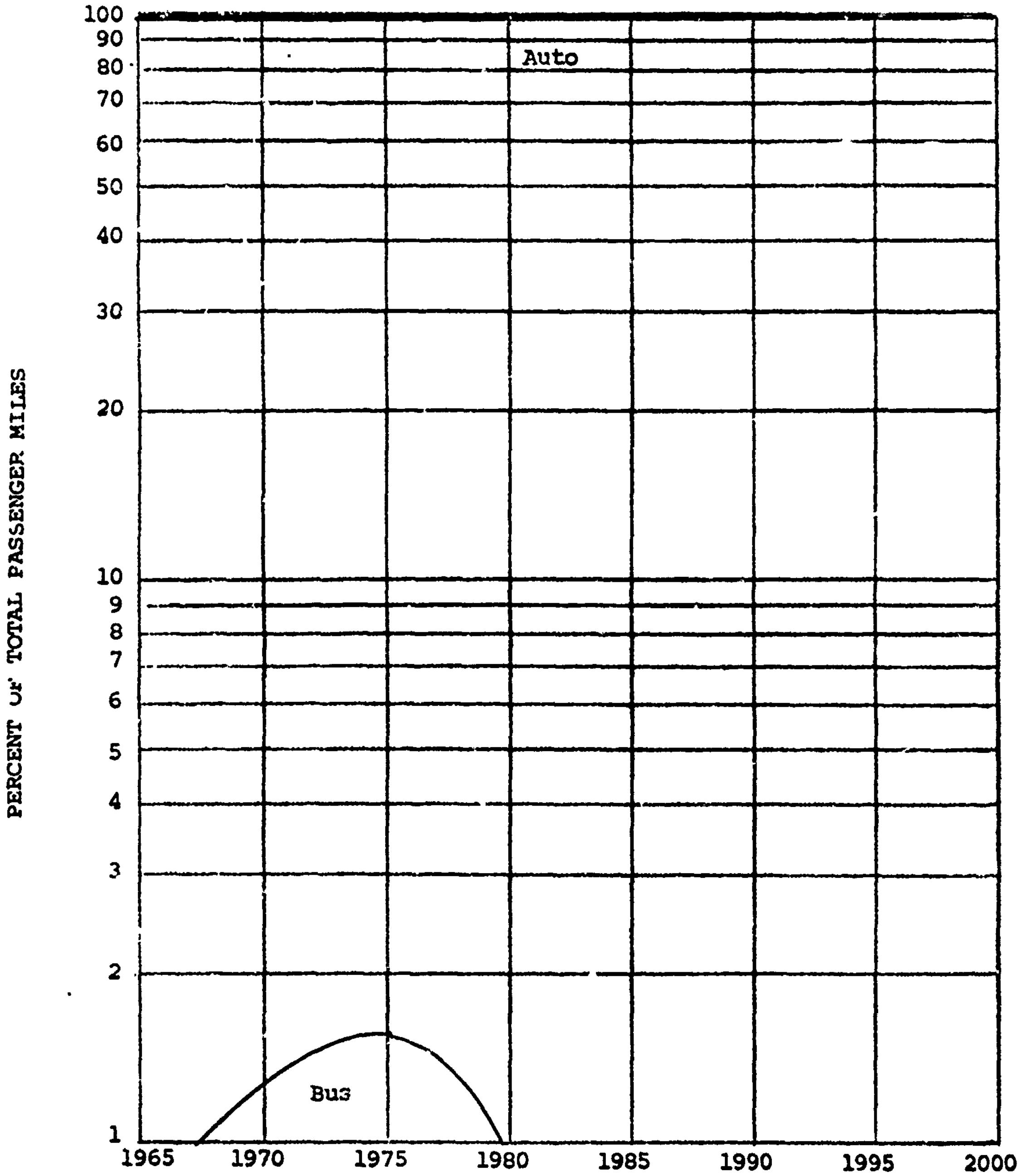
DISTANCE INTERVAL: 0 - 2.5 Miles

NO. OF PASSENGERS: 1

AVERAGE DISTANCE : 1 Mile

NO. OF PASSENGERS WITH TIME VALUE : 1

FIGURE AB-2
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Non-urban

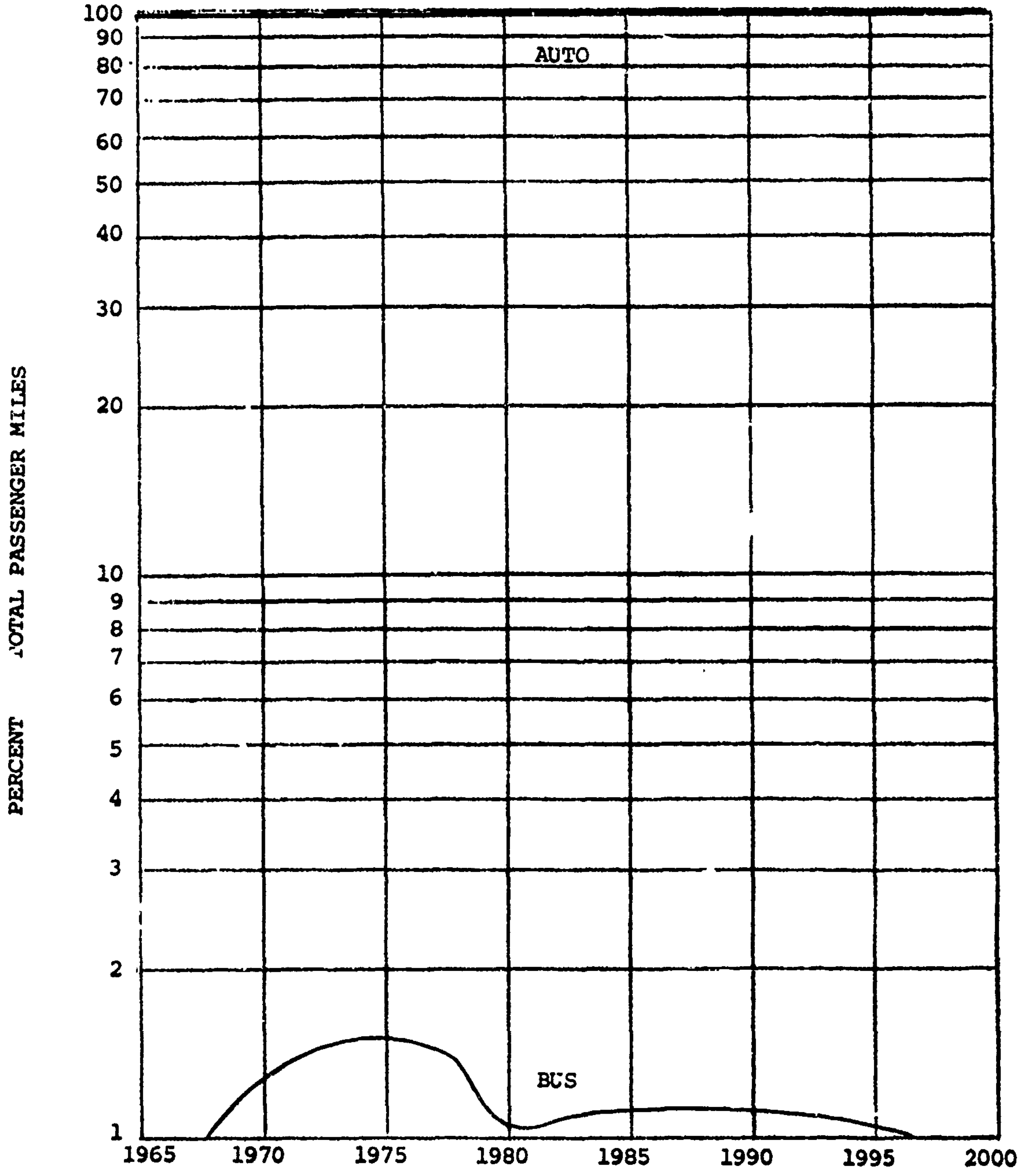
DISTANCE INTERVAL: 0-2.5 miles

NO. OF PASSENGERS: 2

AVERAGE DISTANCE : 1 mile

NO. OF PASSENGERS WITH TIME VALUE : 2

FIGURE AB-4
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Non-Urban

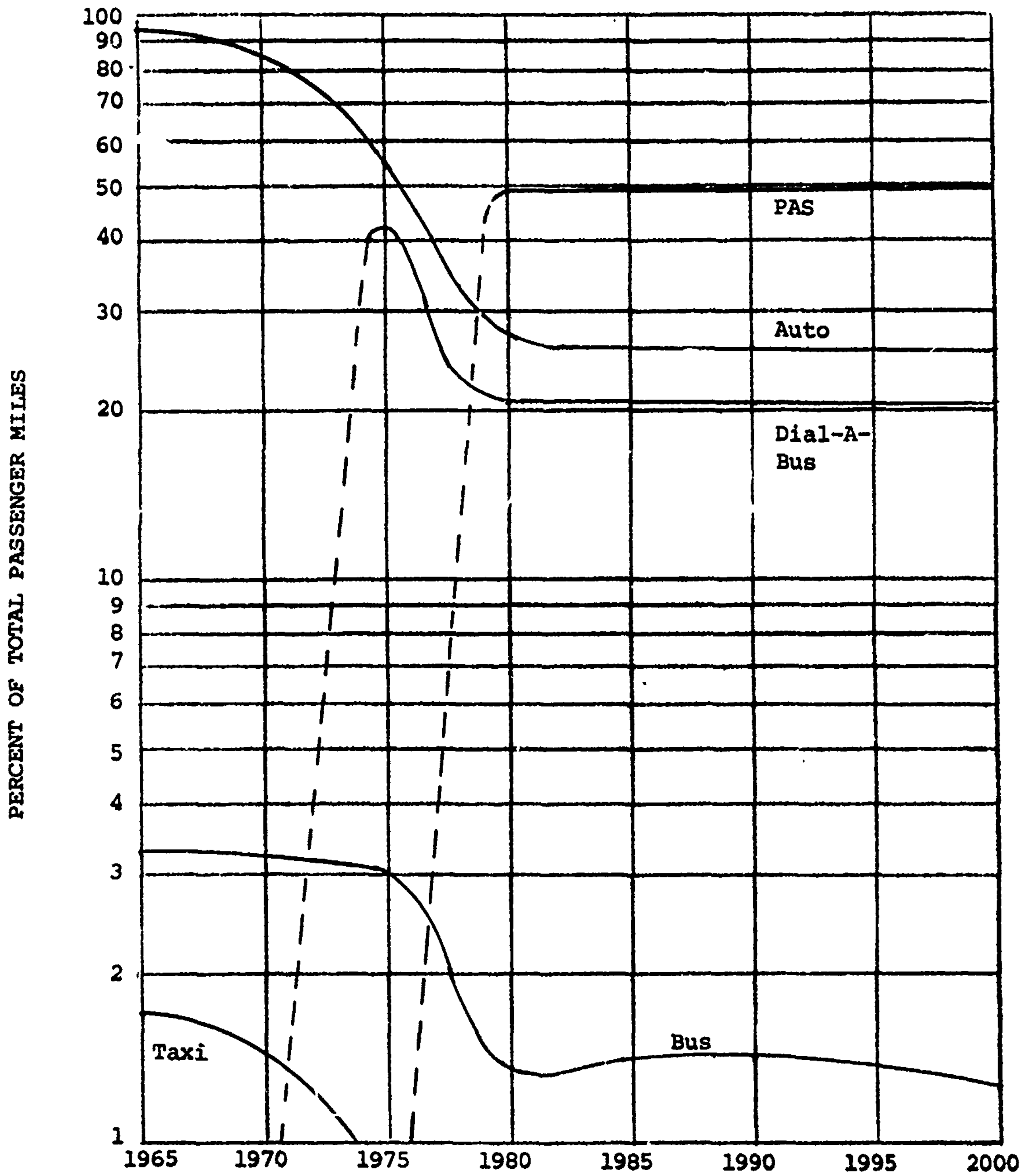
DISTANCE INTERVAL: 0-2.5 Miles

NO. OF PASSENGERS: 4

AVERAGE DISTANCE : 1 Mile

NO. OF PASSENGERS WITH TIME VALUE : 4

FIGURE AC-1
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Other Urban

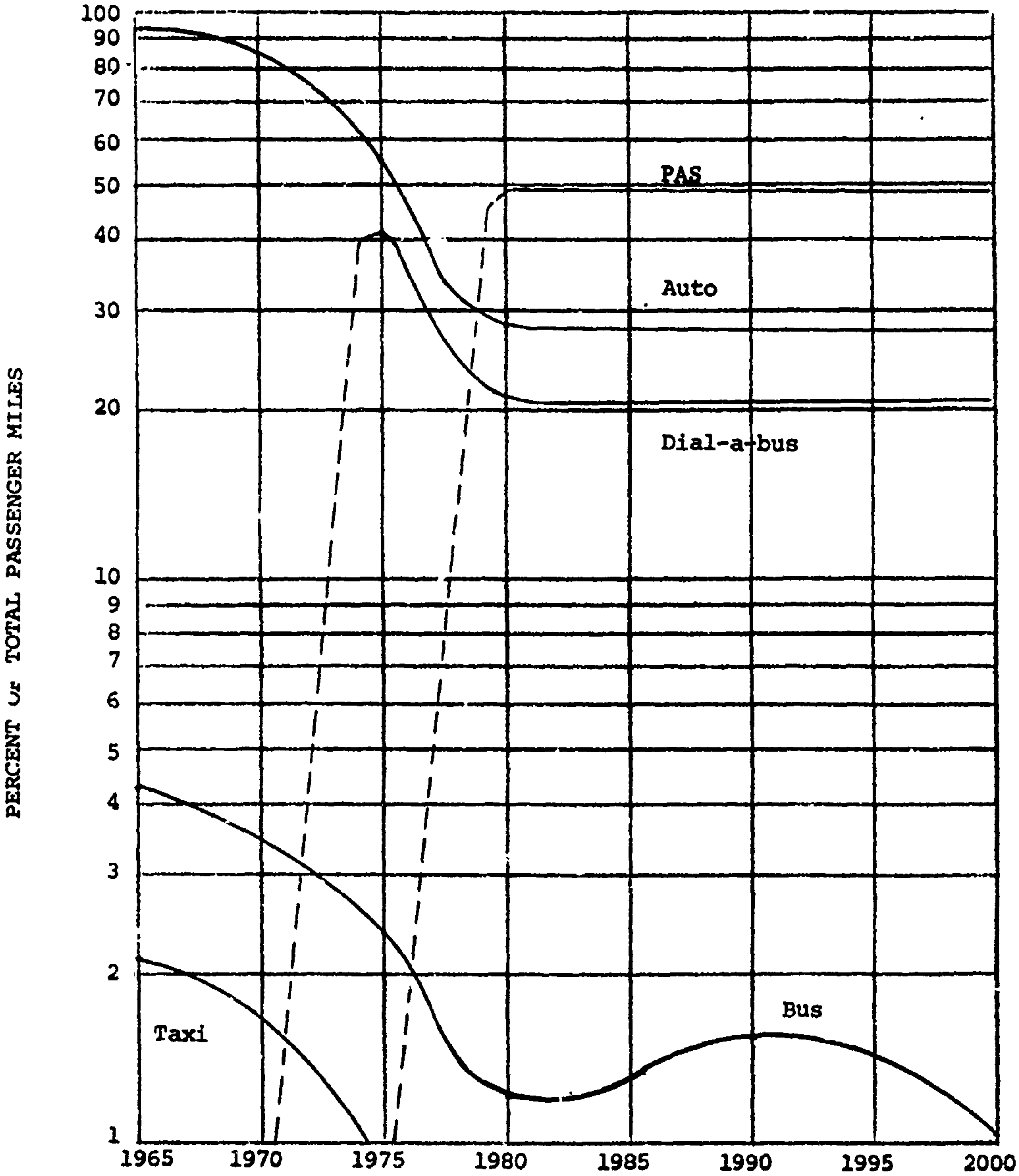
DISTANCE INTERVAL: 0 - 2.5 Miles

NO. OF PASSENGERS: 1

AVERAGE DISTANCE : 1 Mile

NO. OF PASSENGERS WITH TIME VALUE : 1

FIGURE AC-2
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Other urban

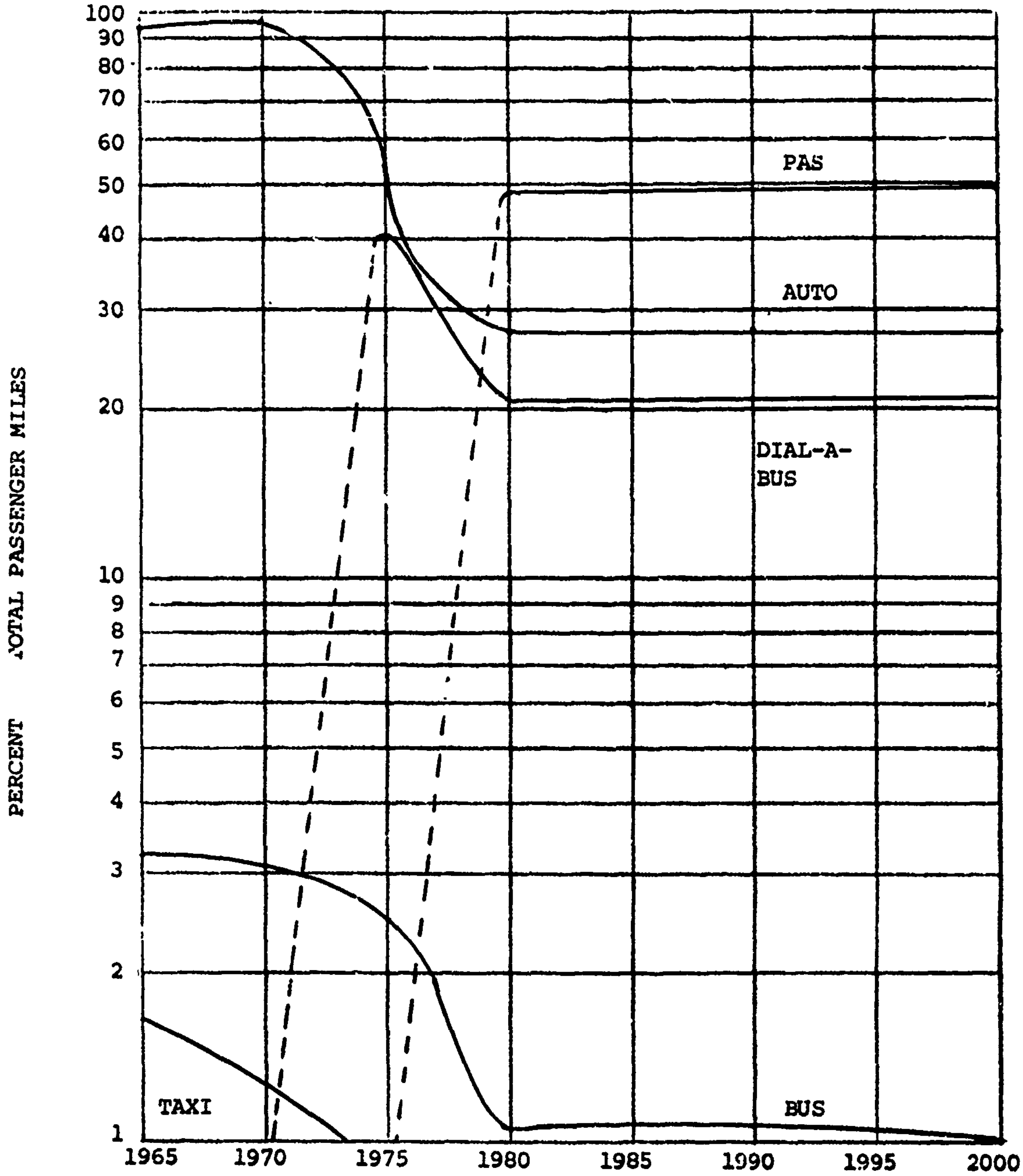
DISTANCE INTERVAL: 0-2.5 miles

NO. OF PASSENGERS: 2

AVERAGE DISTANCE : 1 mile

NO. OF PASSENGERS WITH TIME VALUE : 2

FIGURE AC-4
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



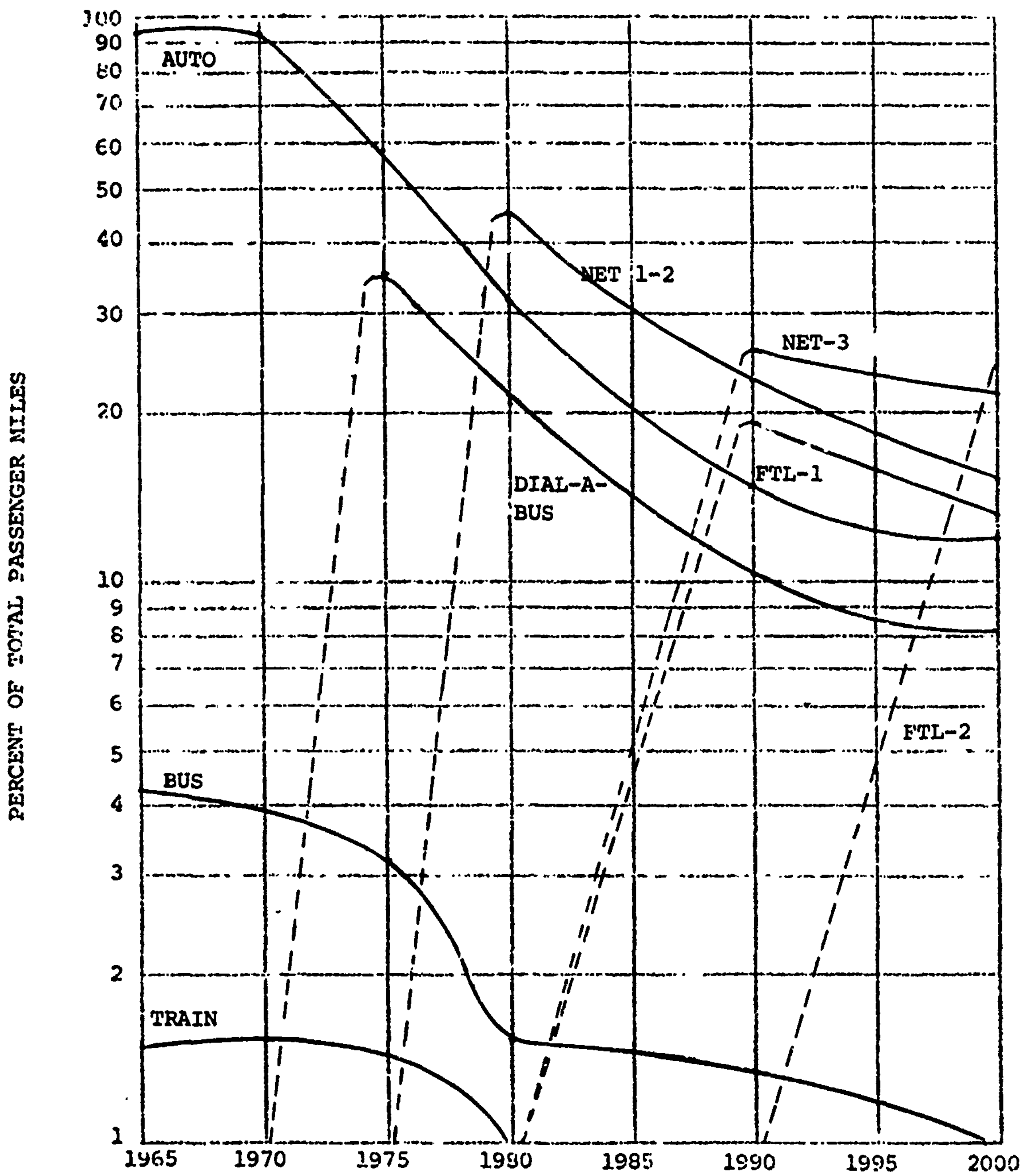
LEGEND

LOCATION: Other Urban

DISTANCE INTERVAL: 0-2.5 Miles   NO. OF PASSENGERS: 4

AVERAGE DISTANCE : 1 Mile   NO. OF PASSENGERS WITH TIME VALUE : 4

FIGURE BB-1
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



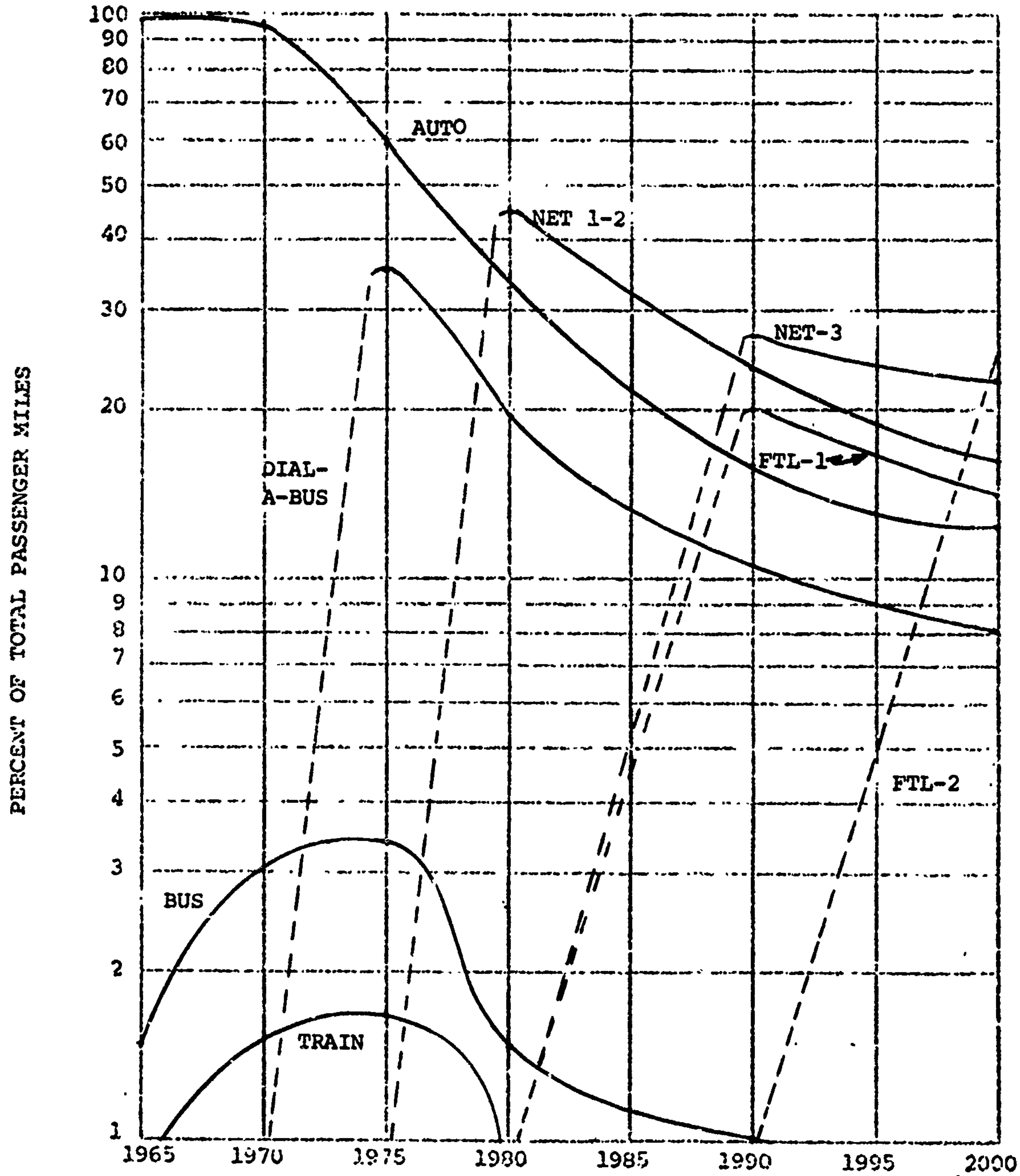
LEGEND

LOCATION: Urban

DISTANCE INTERVAL: 2.5-20 Miles NO. OF PASSENGERS: 1

AVERAGE DISTANCE : 8.5 Miles NO. OF PASSENGERS WITH TIME VALUE : 1

FIGURE BB-2
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



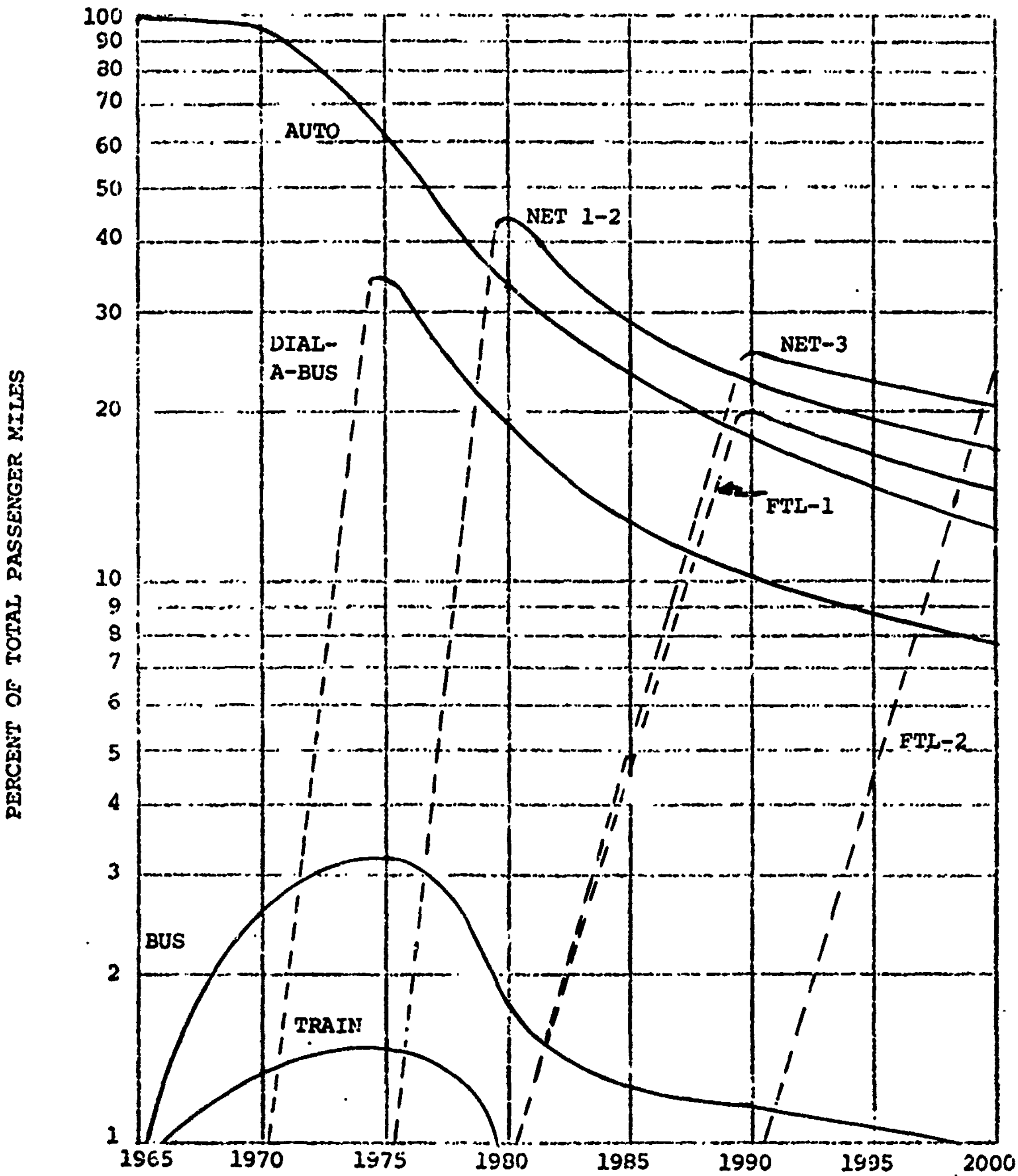
LEGEND

LOCATION: Urban

DISTANCE INTERVAL: 2.5-20 Miles NO. OF PASSENGERS: 2

AVERAGE DISTANCE : 8.5 Miles NO. OF PASSENGERS WITH TIME VALUE : 2

FIGURE BB-4
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Urban

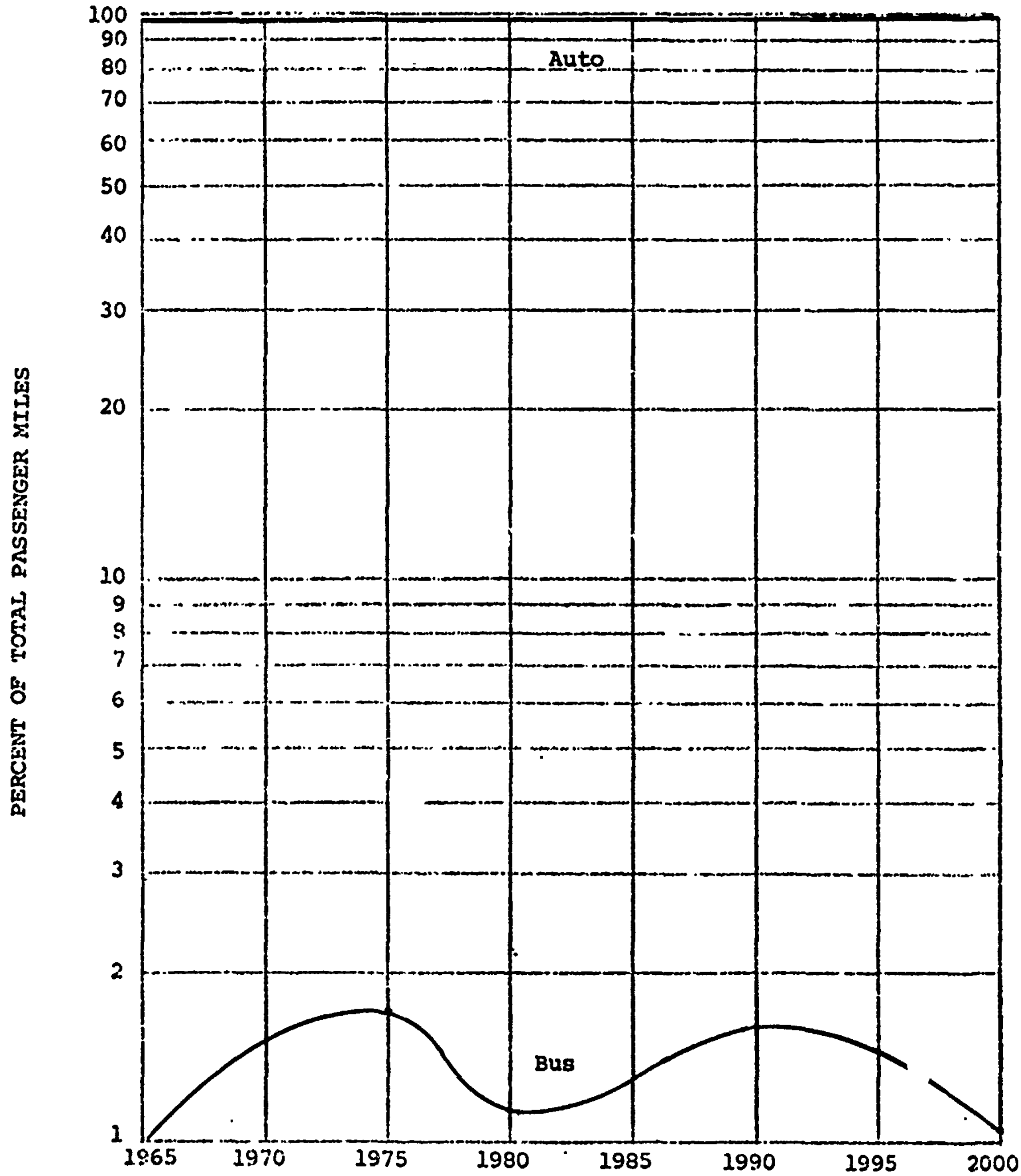
DISTANCE INTERVAL: 2.5-20 Miles

NO. OF PASSENGERS: 4

AVERAGE DISTANCE : 8.5 Miles

NO. OF PASSENGERS WITH TIME VALUE : 4

FIGURE BC-1
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Non-urban

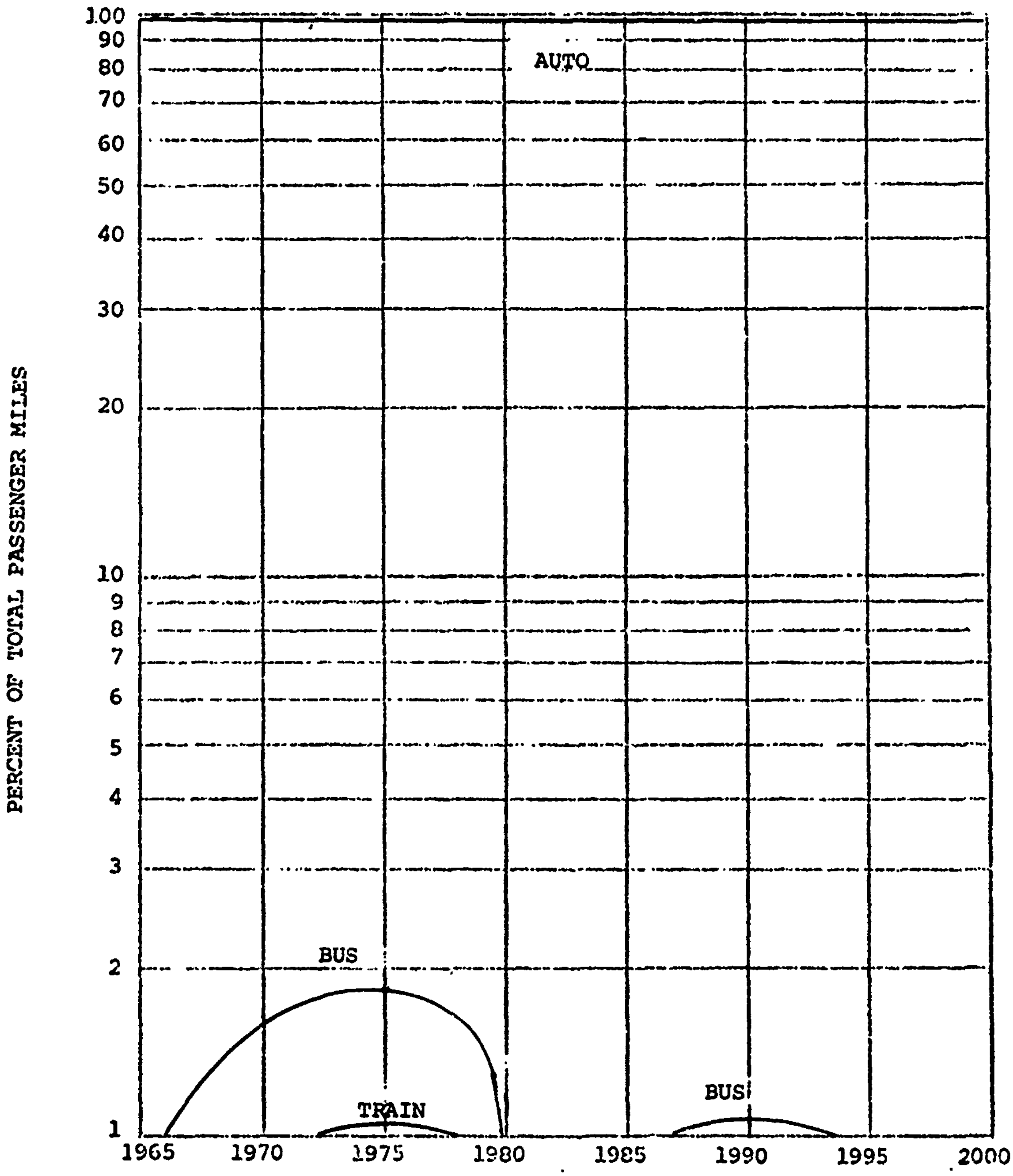
DISTANCE INTERVAL: 2.5-20 miles

NO. OF PASSENGERS: 1

AVERAGE DISTANCE : 8.5 miles

NO. OF PASSENGERS WITH TIME VALUE : 1

FIGURE BC-2
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



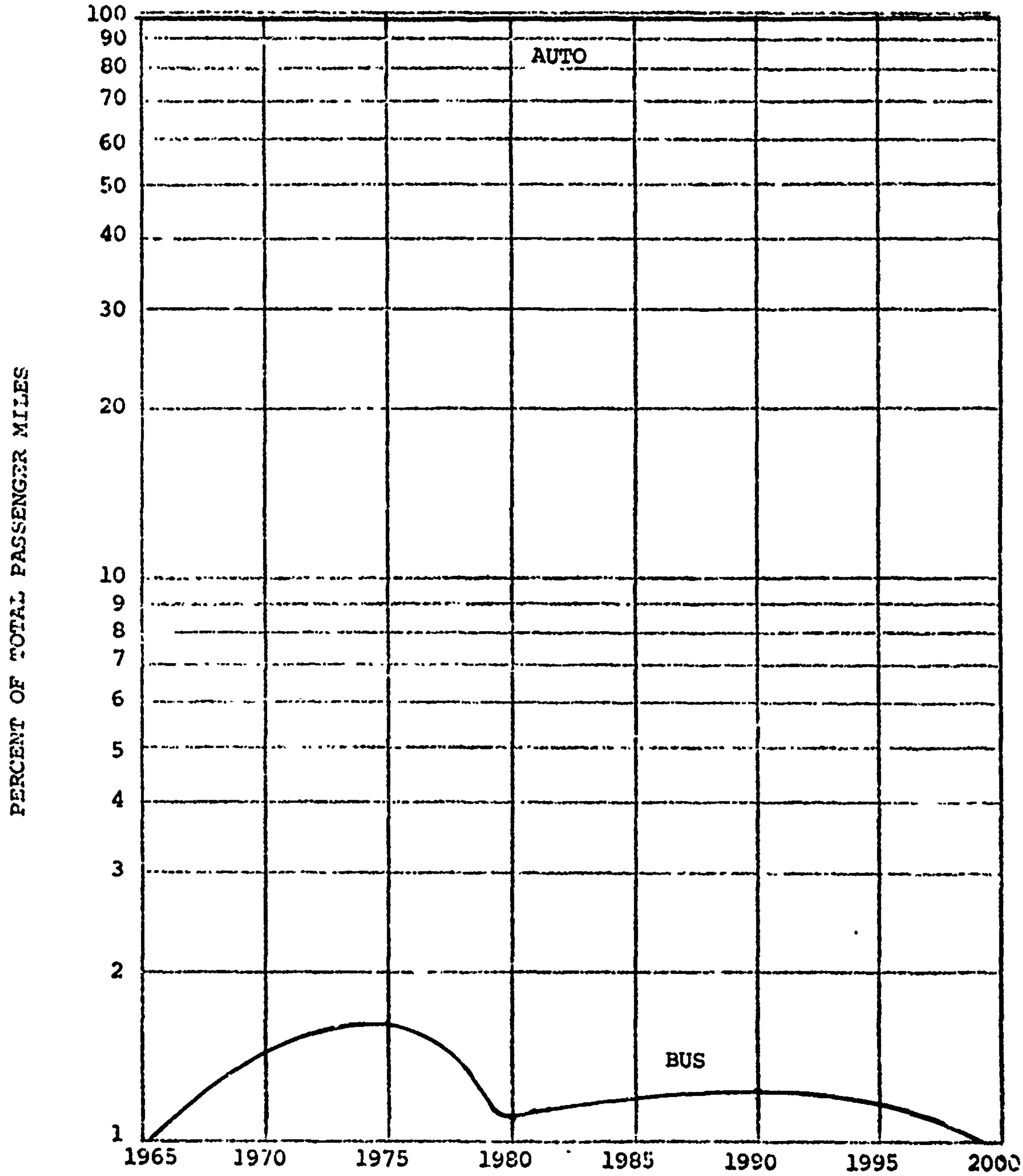
LEGEND

LOCATION: Non-Urban

DISTANCE INTERVAL: 2.5-20 Miles   NO. OF PASSENGERS: 2

AVERAGE DISTANCE : 8.5 Miles   NO. OF PASSENGERS WITH TIME VALUE : 2

FIGURE BC-4
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Non-Urban

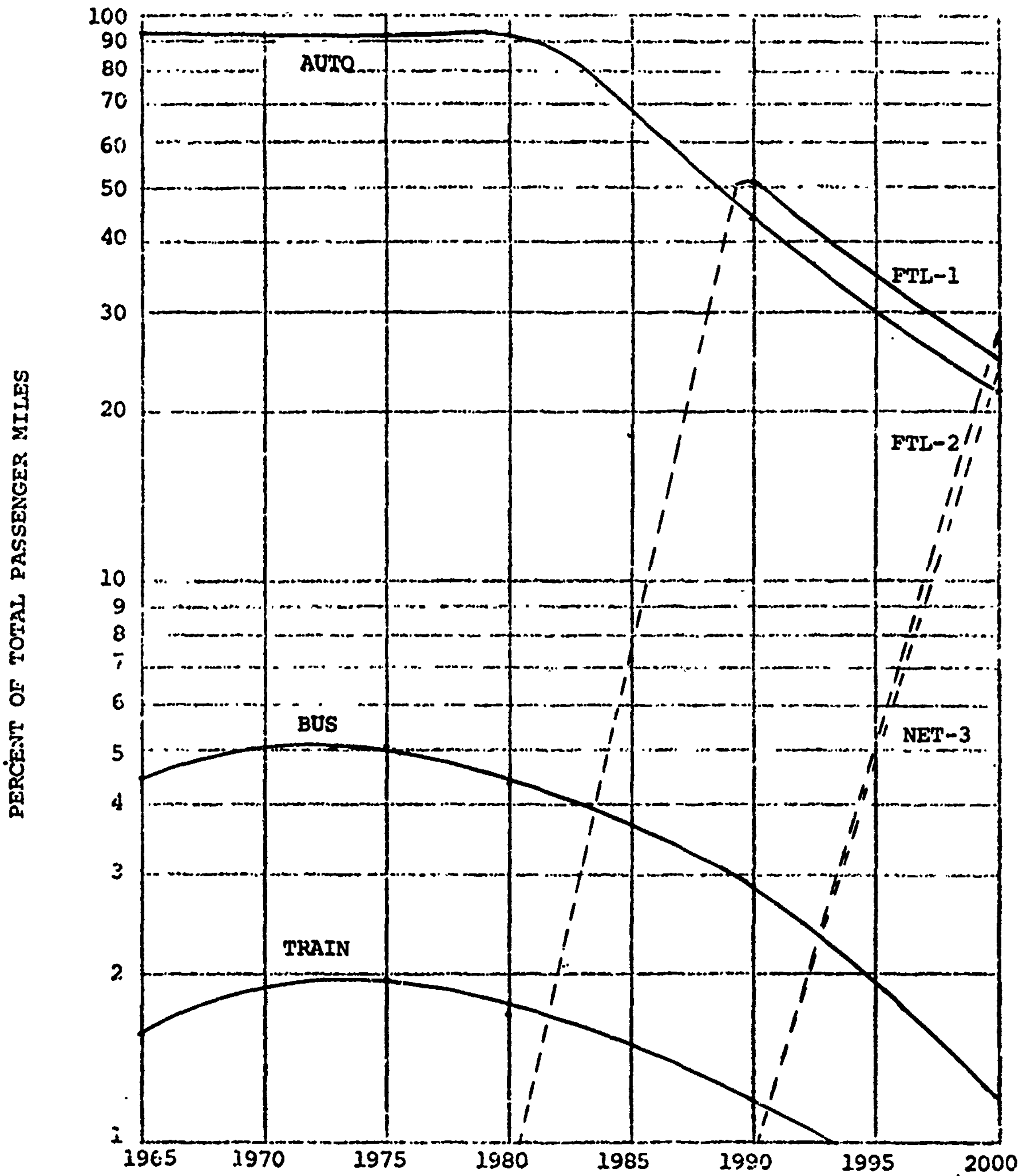
DISTANCE INTERVAL: 2.5-20 Miles

NO. OF PASSENGERS: 4

AVERAGE DISTANCE : 8.5 Miles

NO. OF PASSENGERS
WITH TIME VALUE : 4

FIGURE CC-1
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Urban

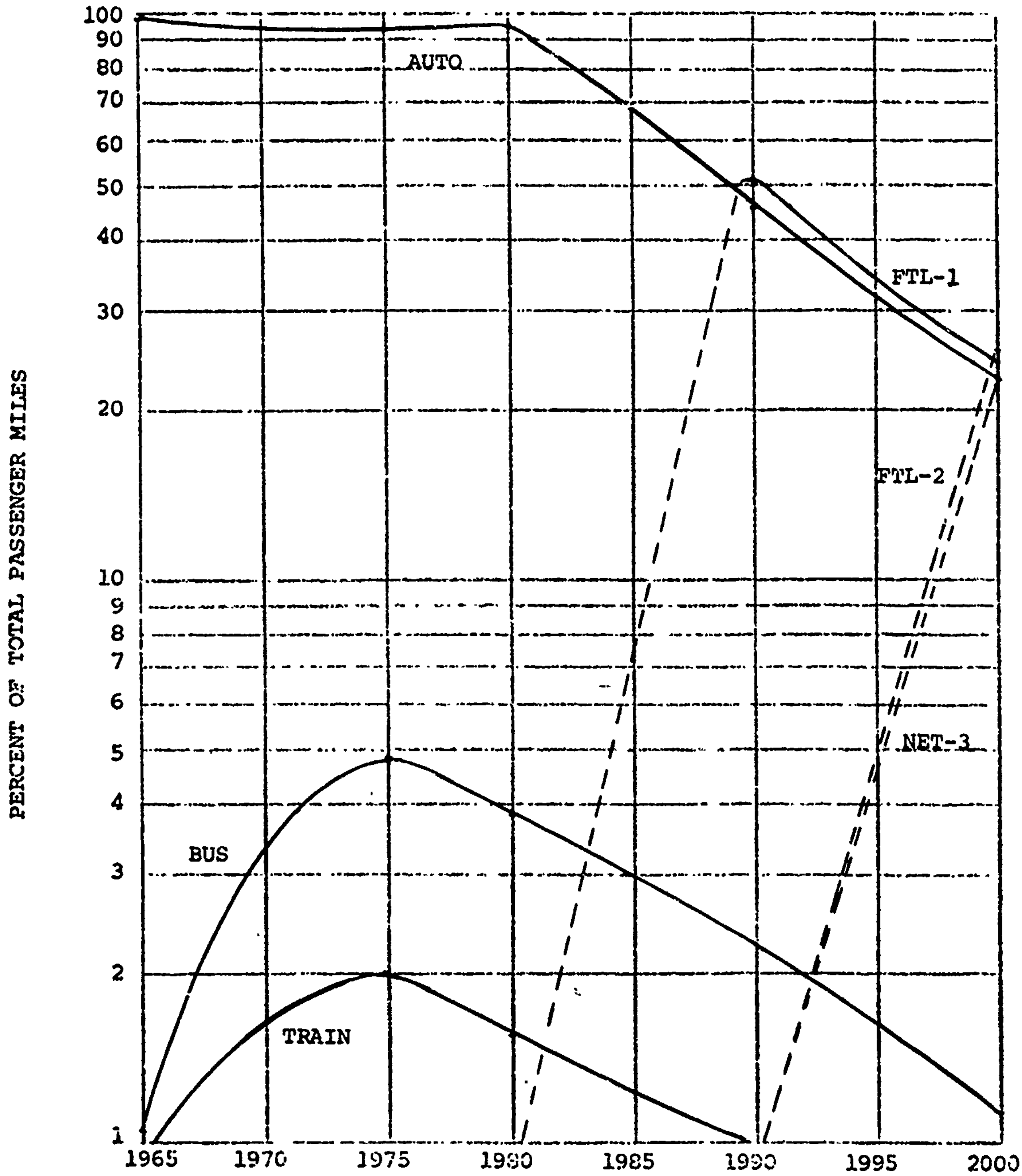
DISTANCE INTERVAL: 20-50 miles

NO. OF PASSENGERS: 1

AVERAGE DISTANCE : 30 miles

NO. OF PASSENGERS WITH TIME VALUE : 1

FIGURE CC-2
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Urban

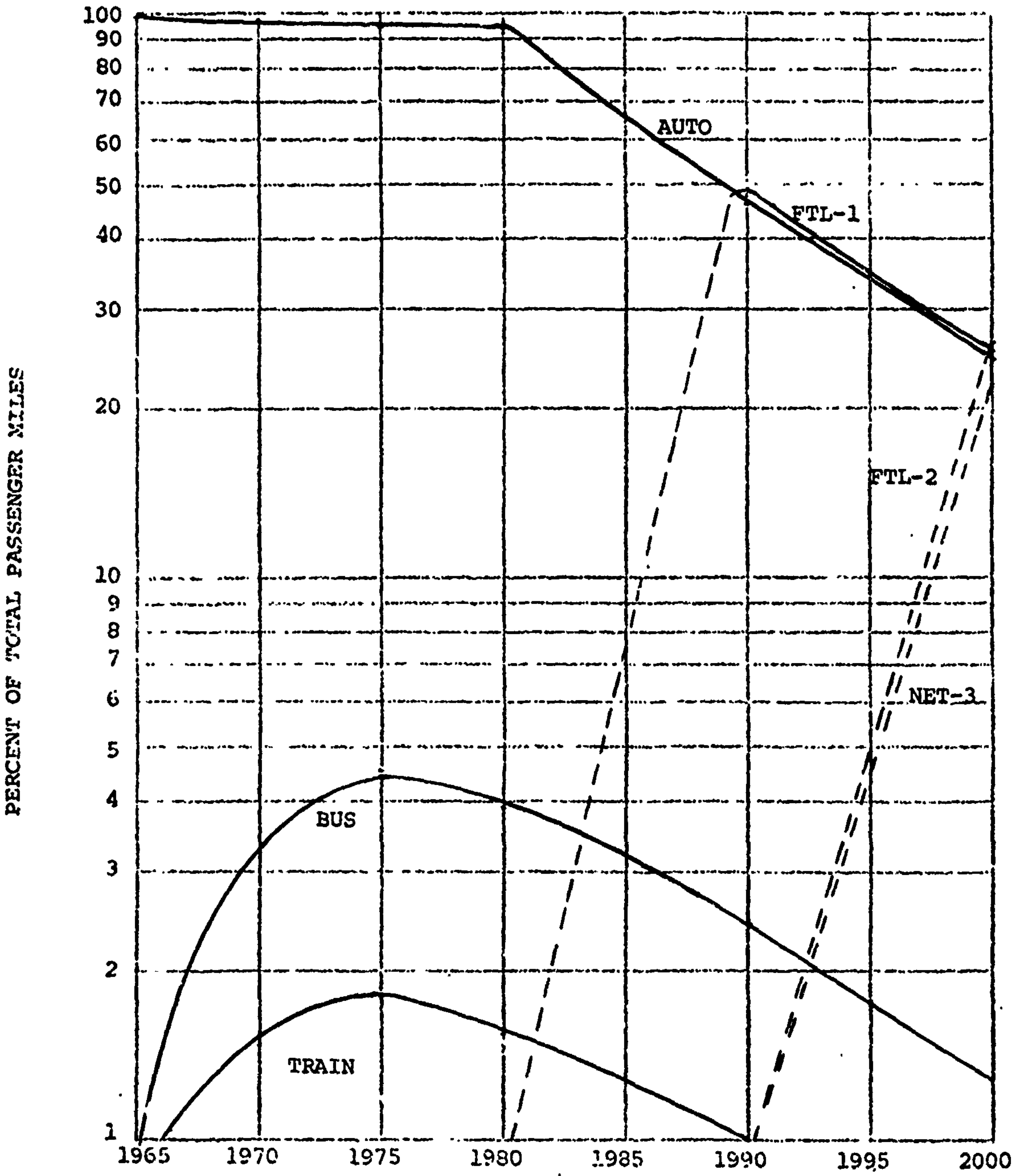
DISTANCE INTERVAL: 20-50 Miles

NO. OF PASSENGERS: 2

AVERAGE DISTANCE : 30 Miles

NO. OF PASSENGERS WITH TIME VALUE : 2

FIGURE CC-4
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Urban

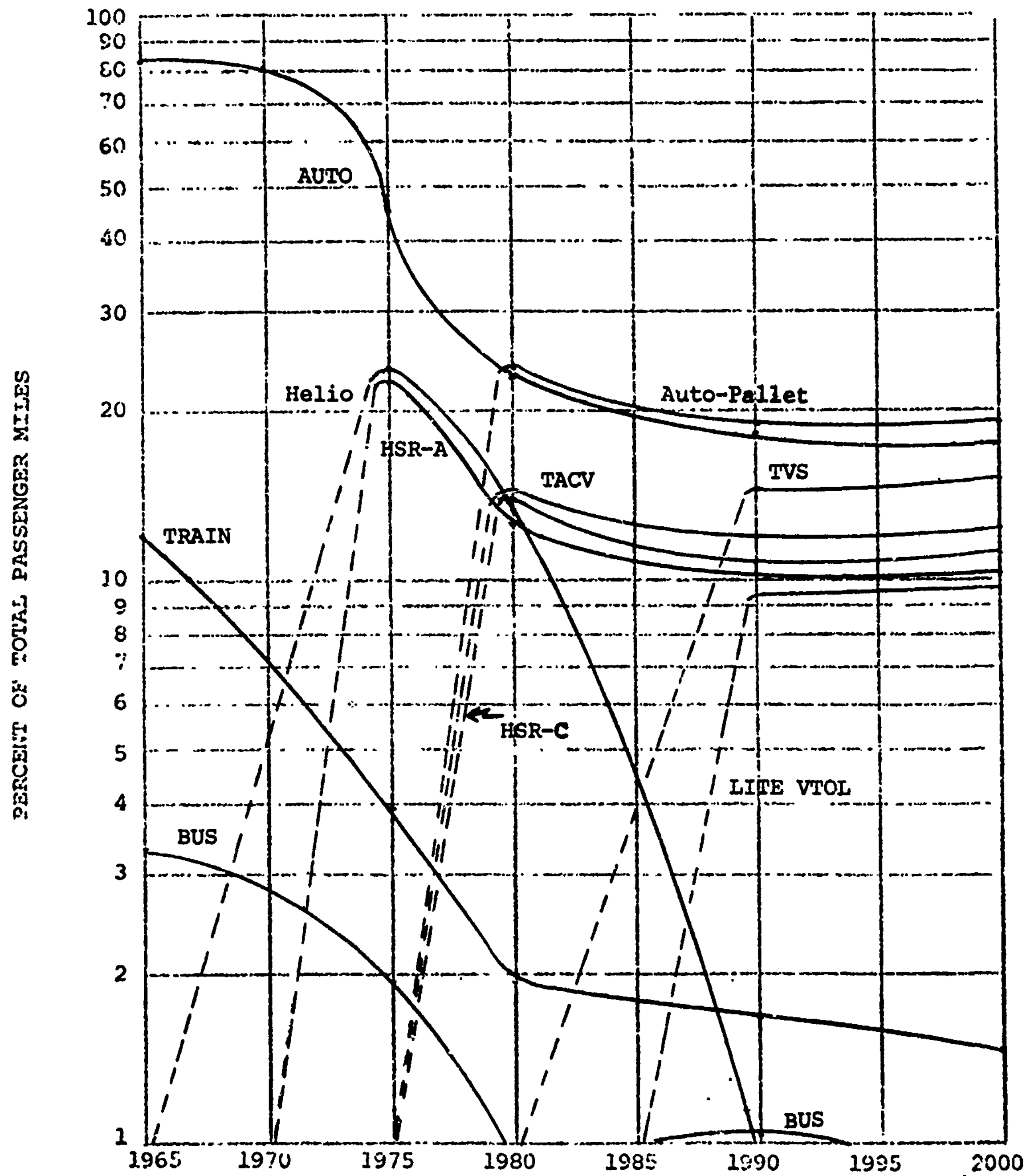
DISTANCE INTERVAL: 20-50 Miles

NO. OF PASSENGERS: 4

AVERAGE DISTANCE : 30 Miles

NO. OF PASSENGERS
WITH TIME VALUE : 4

FIGURE CD-1
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Non-Urban

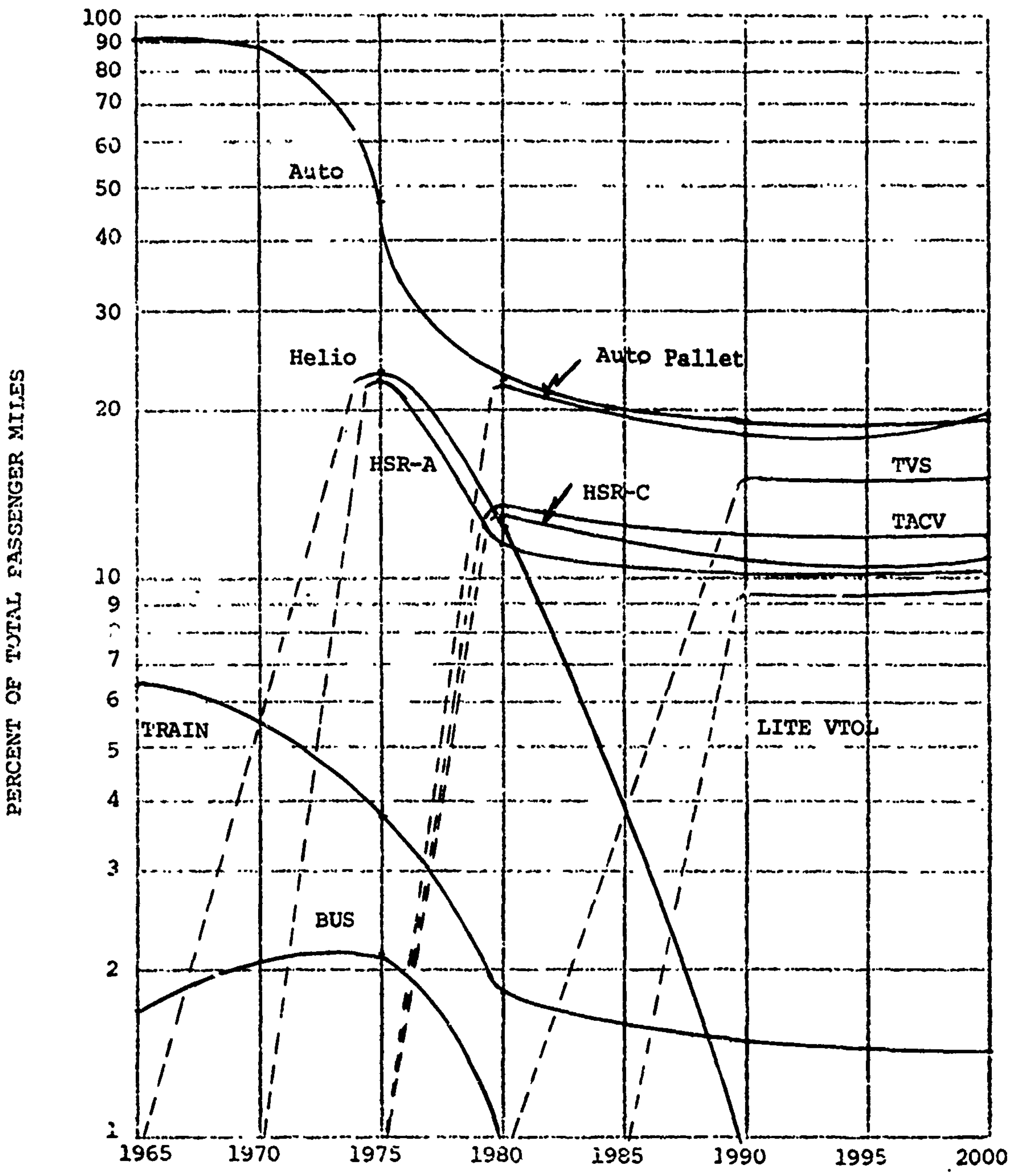
DISTANCE INTERVAL: 20-50 miles

NO. OF PASSENGERS: 1

AVERAGE DISTANCE : 24 miles

NO. OF PASSENGERS WITH TIME VALUE : 1

FIGURE CD-2
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Non-Urban

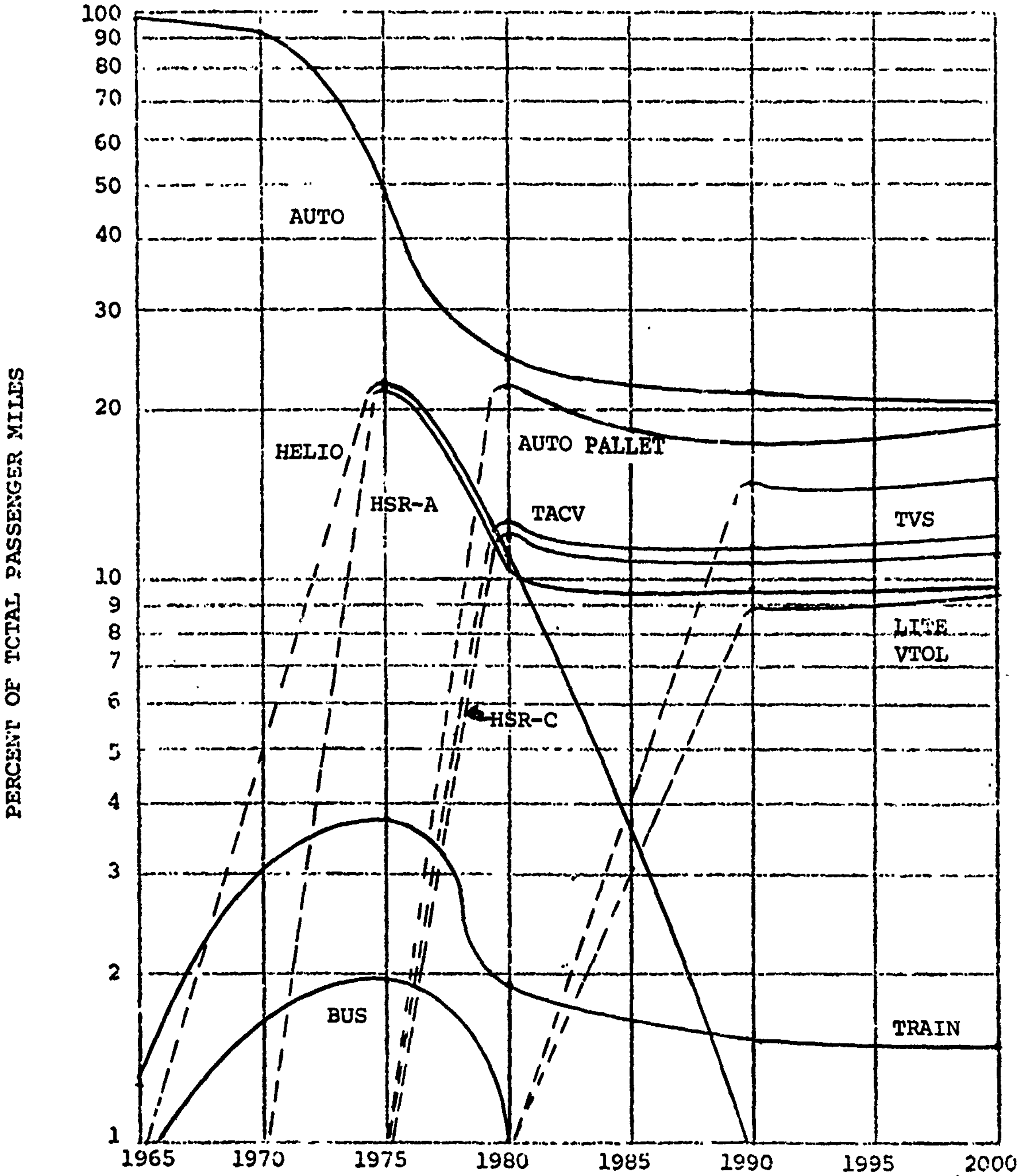
DISTANCE INTERVAL: 20-50 miles

NO. OF PASSENGERS: 2

AVERAGE DISTANCE : 24 miles

NO. OF PASSENGERS WITH TIME VALUE : 2

FIGURE CD-4
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Non-Urban

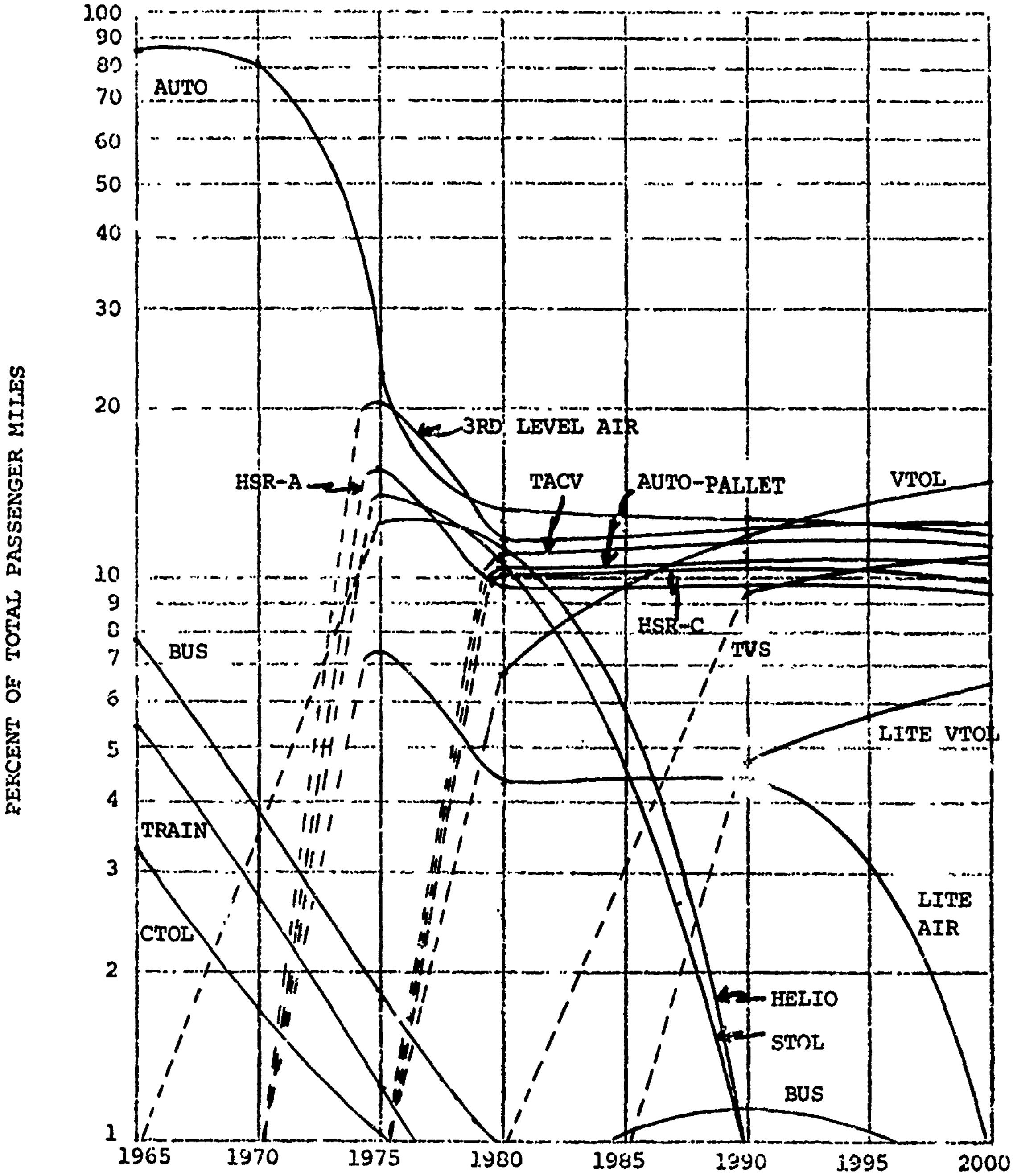
DISTANCE INTERVAL: 20-50 Miles

NO. OF PASSENGERS: 4

AVERAGE DISTANCE : 24 Miles

NO. OF PASSENGERS WITH TIME VALUE : 4

FIGURE DD-1
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Non-Urban

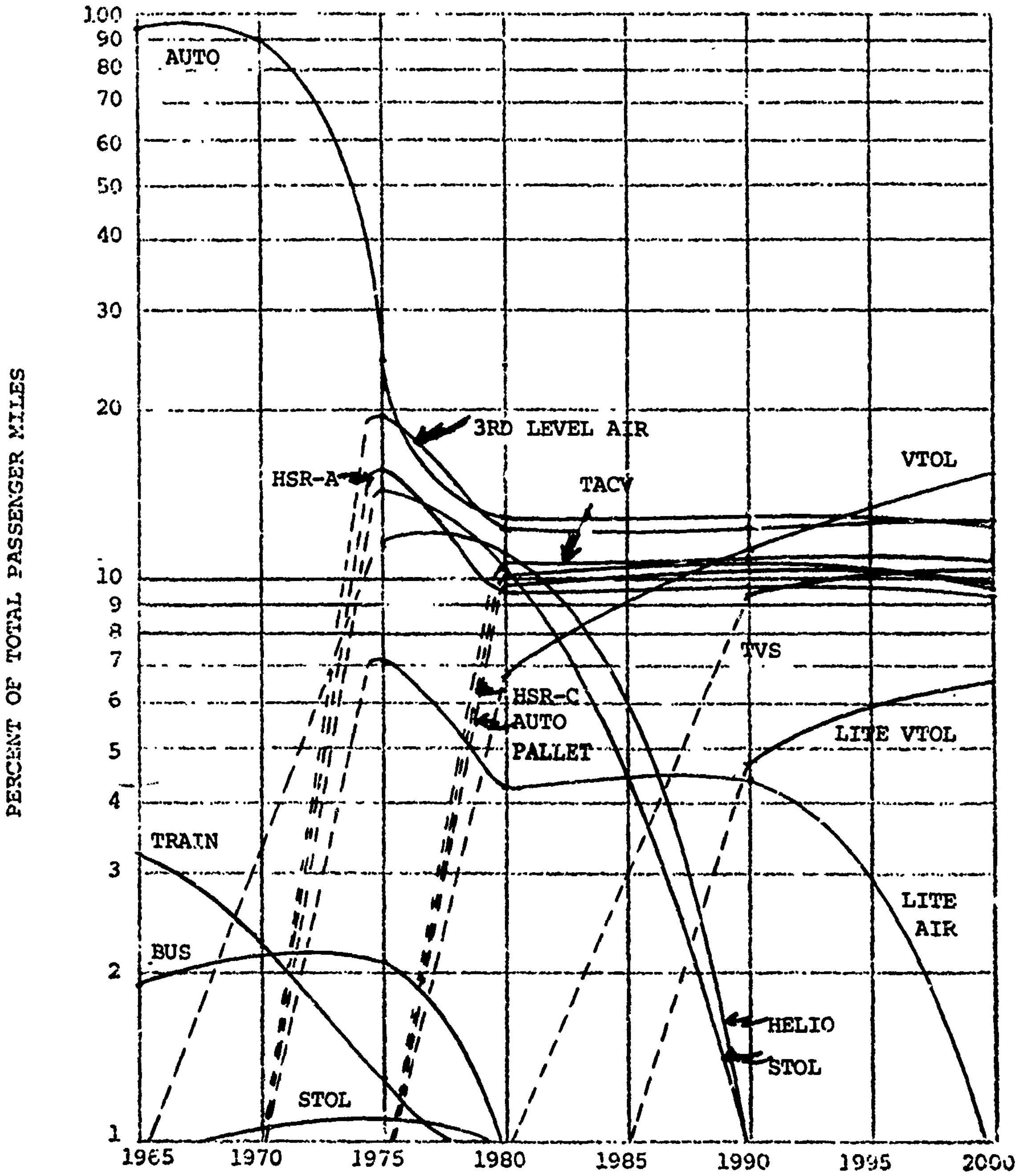
DISTANCE INTERVAL: 50-200 Miles

NO. OF PASSENGERS: 1

AVERAGE DISTANCE : 90 Miles

NO. OF PASSENGERS WITH TIME VALUE : 1

FIGURE DD-2
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Non-Urban

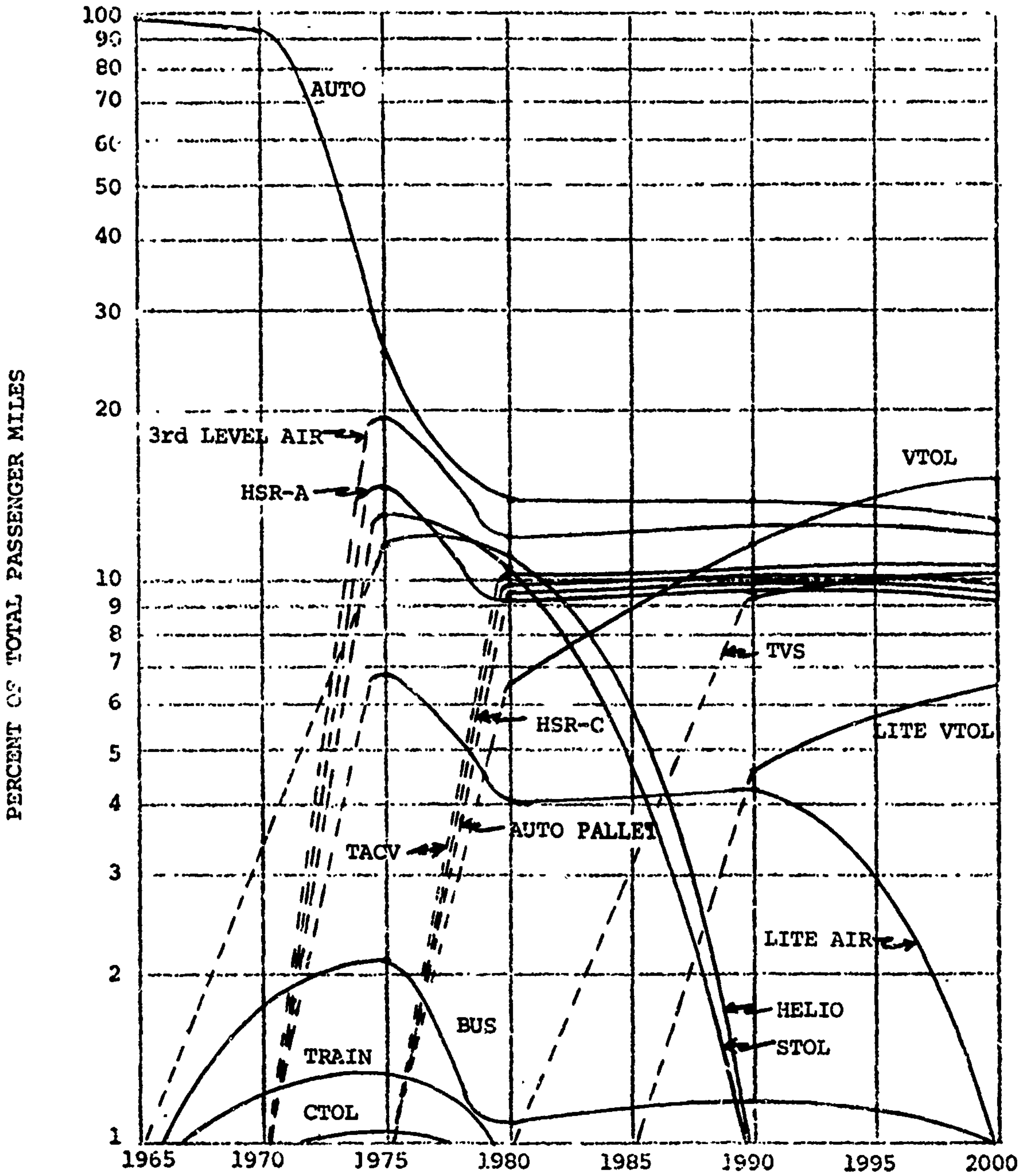
DISTANCE INTERVAL: 50-200 Miles

NO. OF PASSENGERS: 2

AVERAGE DISTANCE : 90 Miles

NO. OF PASSENGERS WITH TIME VALUE : 2

FIGURE DD-4
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



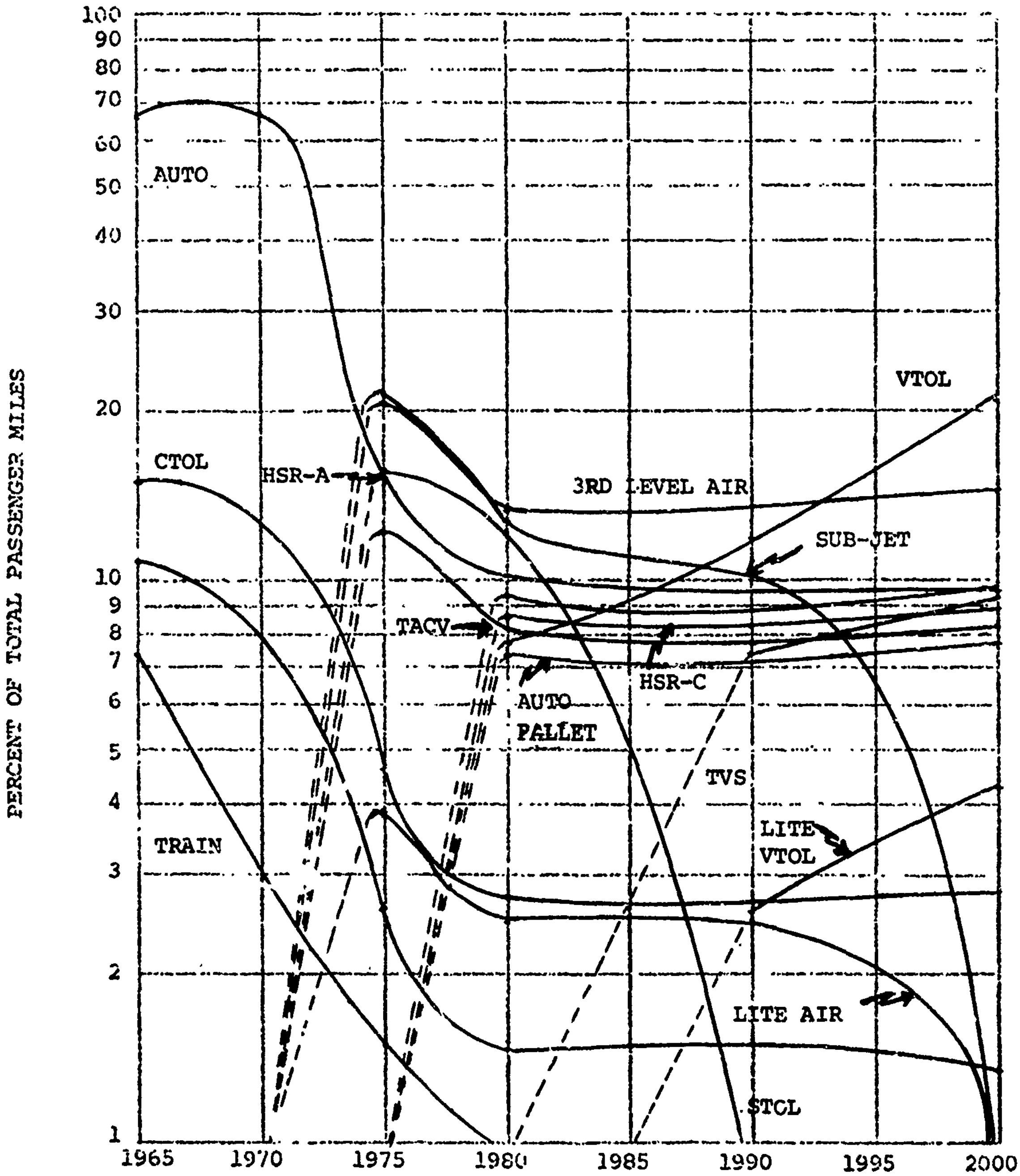
LEGEND

LOCATION: Non-Urban

DISTANCE INTERVAL: 200-500 Miles NO. OF PASSENGERS: 4

AVERAGE DISTANCE : 305 Miles NO. OF PASSENGERS WITH TIME VALUE : 4

FIGURE EE-1
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



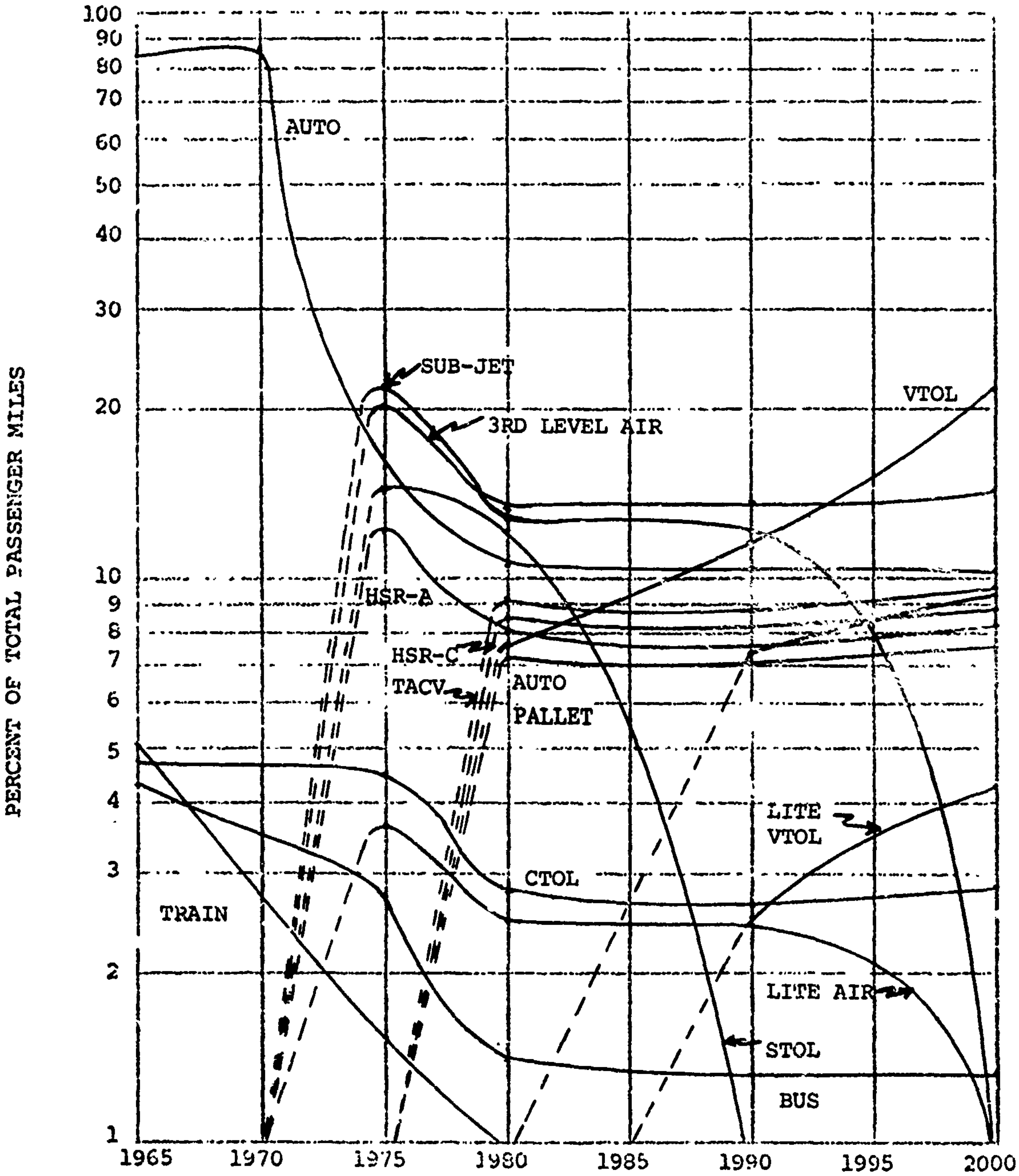
LEGEND

LOCATION: Non-Urban

DISTANCE INTERVAL: 200-500 Miles NO. OF PASSENGERS: 1

AVERAGE DISTANCE : 305 Miles NO. OF PASSENGERS WITH TIME VALUE 1

FIGURE EE-2
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Non-Urban

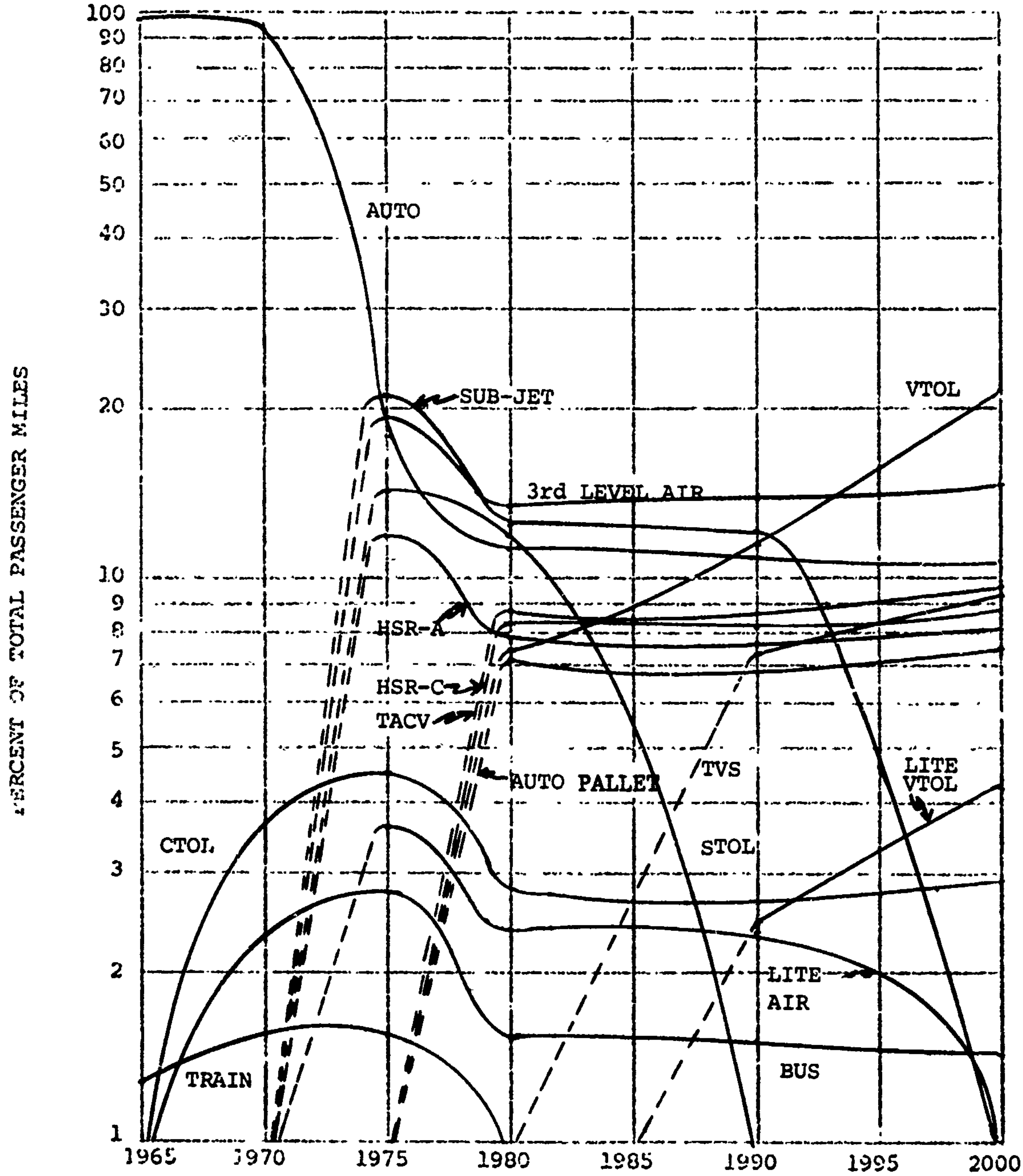
DISTANCE INTERVAL: 200-500 Miles

NO. OF PASSENGERS: 2

AVERAGE DISTANCE : 305 Miles

NO. OF PASSENGERS WITH TIME VALUE : 2

FIGURE EE-4
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Non-Urban

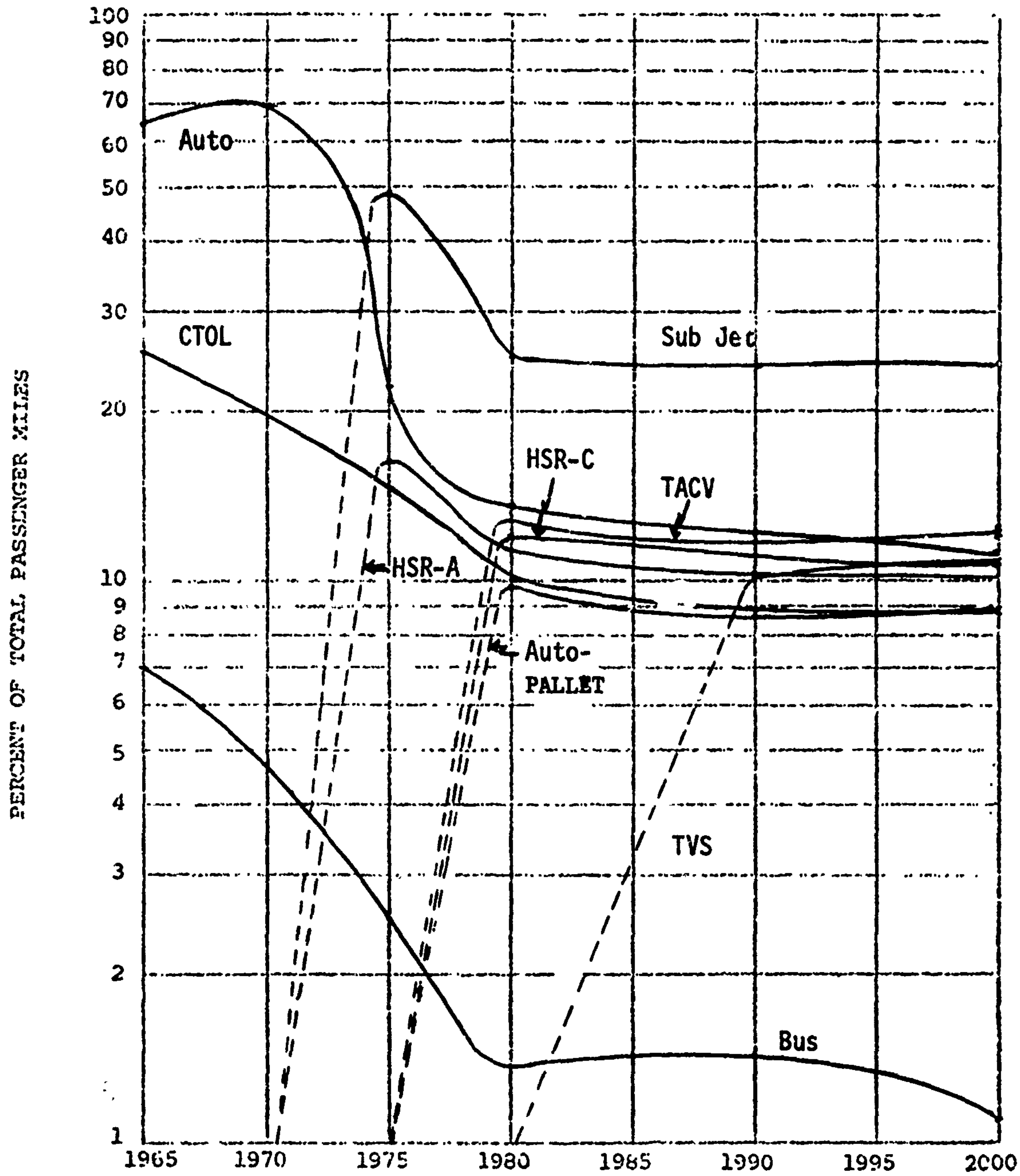
DISTANCE INTERVAL: 200-500 Miles

NO. OF PASSENGERS: 4

AVERAGE DISTANCE : 305 Miles

NO. OF PASSENGERS WITH TIME VALUE : 4

FIGURE FF-1
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



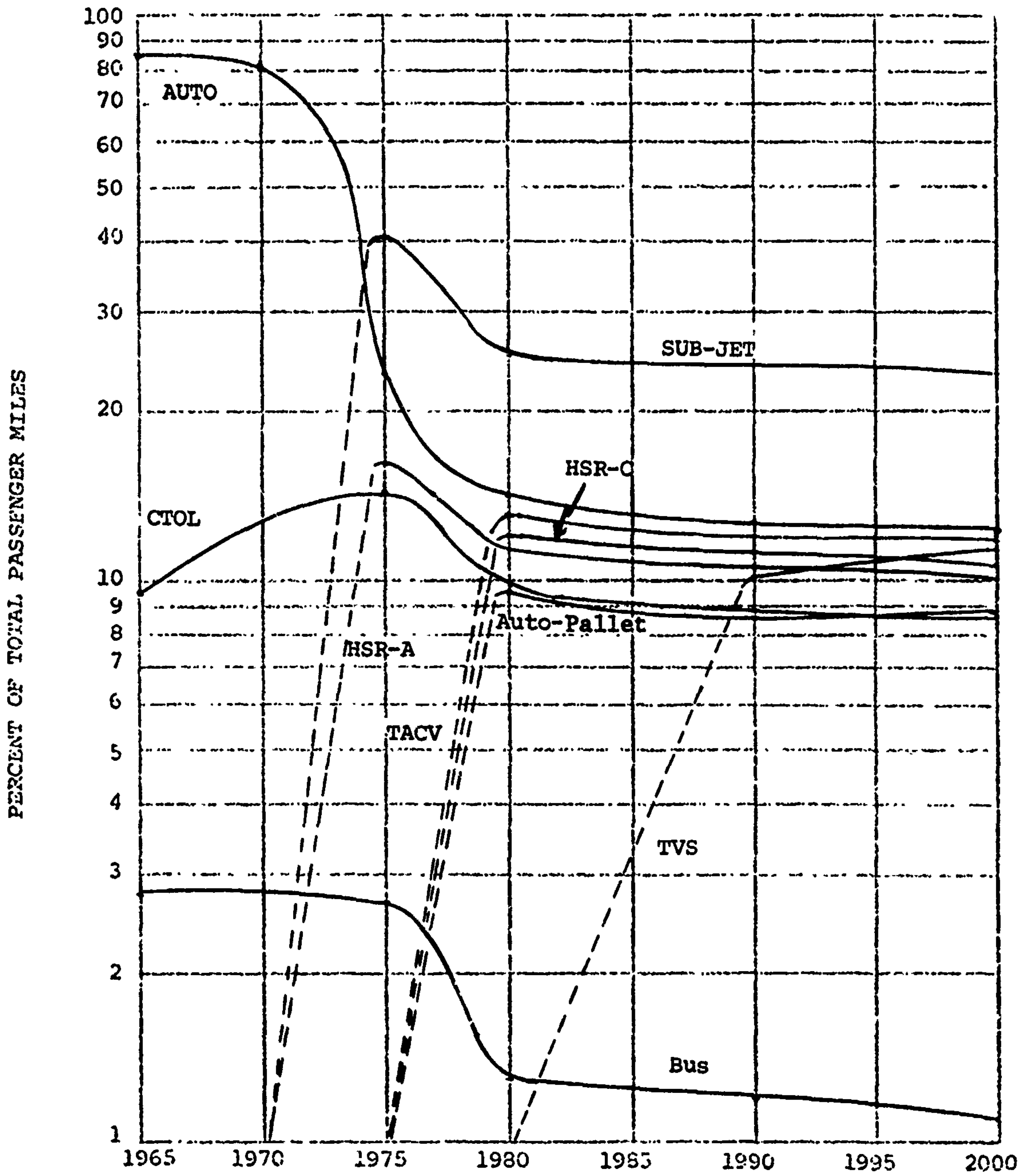
LEGEND

LOCATION: Non-Urban

DISTANCE INTERVAL: 500-1000 Miles   NO. OF PASSENGERS: 1

AVERAGE DISTANCE : 775 Miles   NO. OF PASSENGERS WITH TIME VALUE : 1

FIGURE FF-2
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



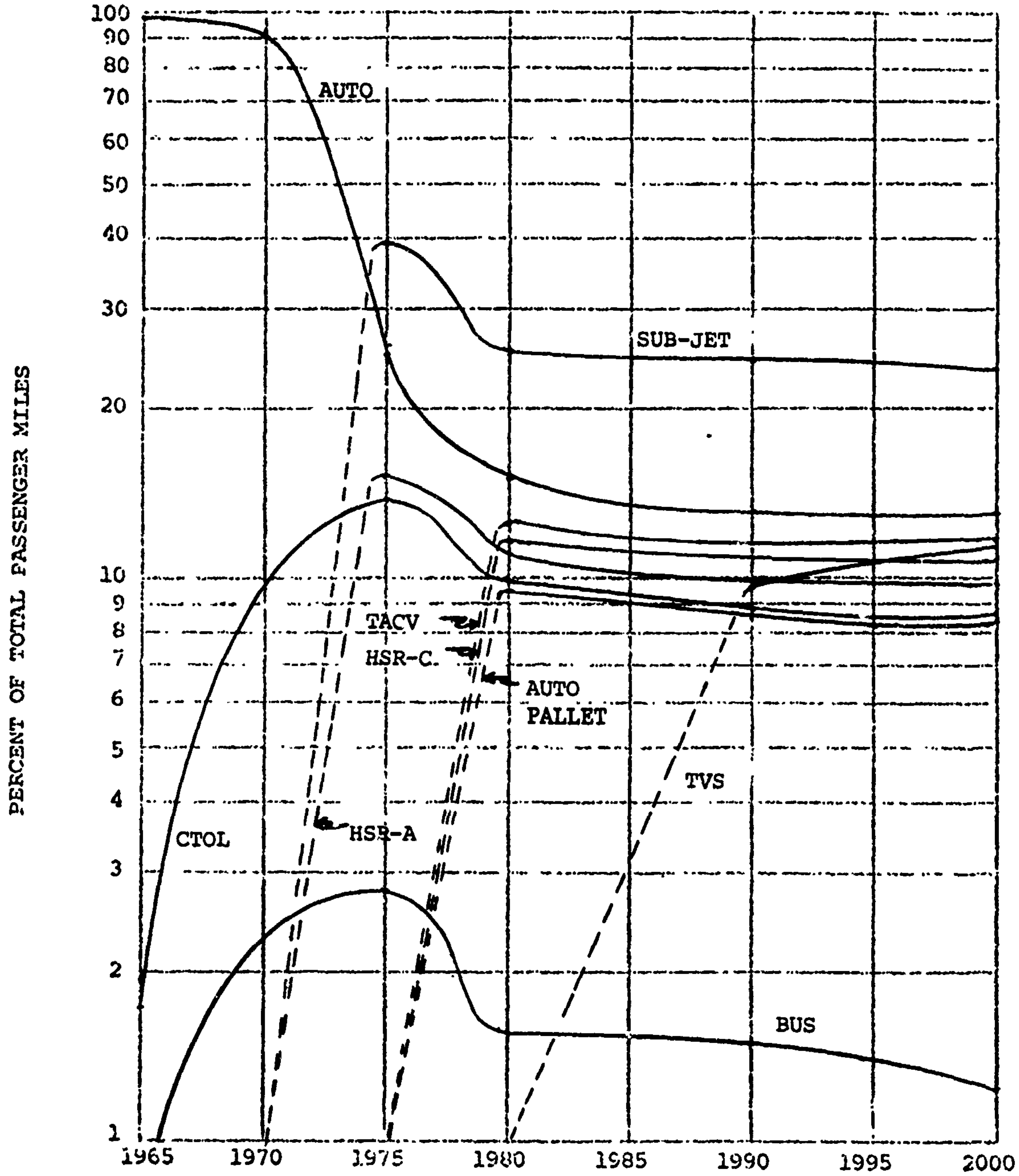
LEGEND

LOCATION: **Non-Urban**

DISTANCE INTERVAL: **500-1000 miles** NO. OF PASSENGERS: **2**

AVERAGE DISTANCE : **775 miles** NO. OF PASSENGERS WITH TIME VALUE : **2**

FIGURE FF-4
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Non-Urban

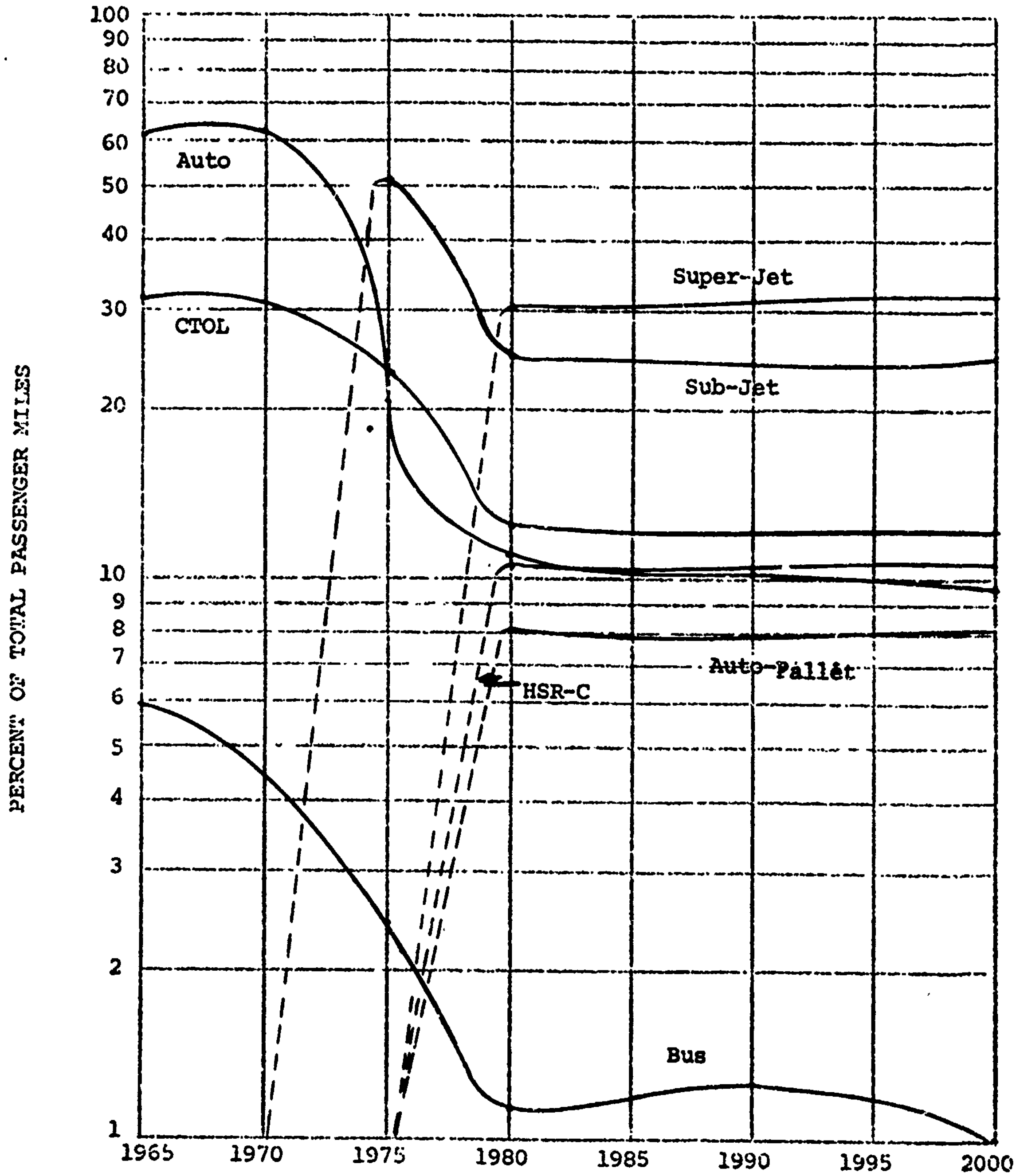
DISTANCE INTERVAL: 500-1000 Miles

NO. OF PASSENGERS: 4

AVERAGE DISTANCE : 775 Miles

NO. OF PASSENGERS WITH TIME VALUE : 4

FIGURE GG-1
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



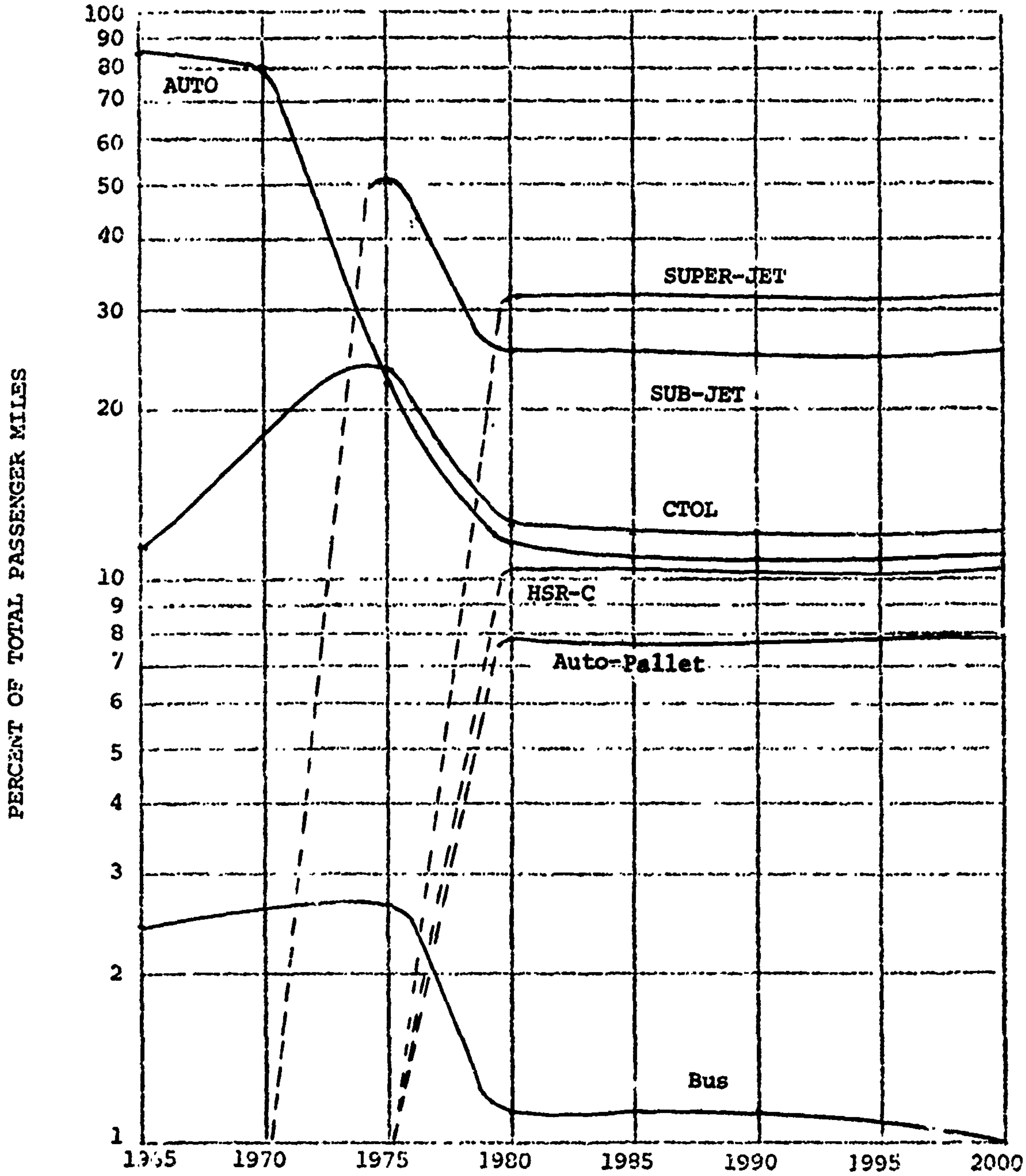
LEGEND

LOCATION: Non-urban

DISTANCE INTERVAL: 1000-3500 miles NO. OF PASSENGERS: 1

AVERAGE DISTANCE : 1400 miles NO. OF PASSENGERS WITH TIME VALUE : 1

FIGURE GG-2
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



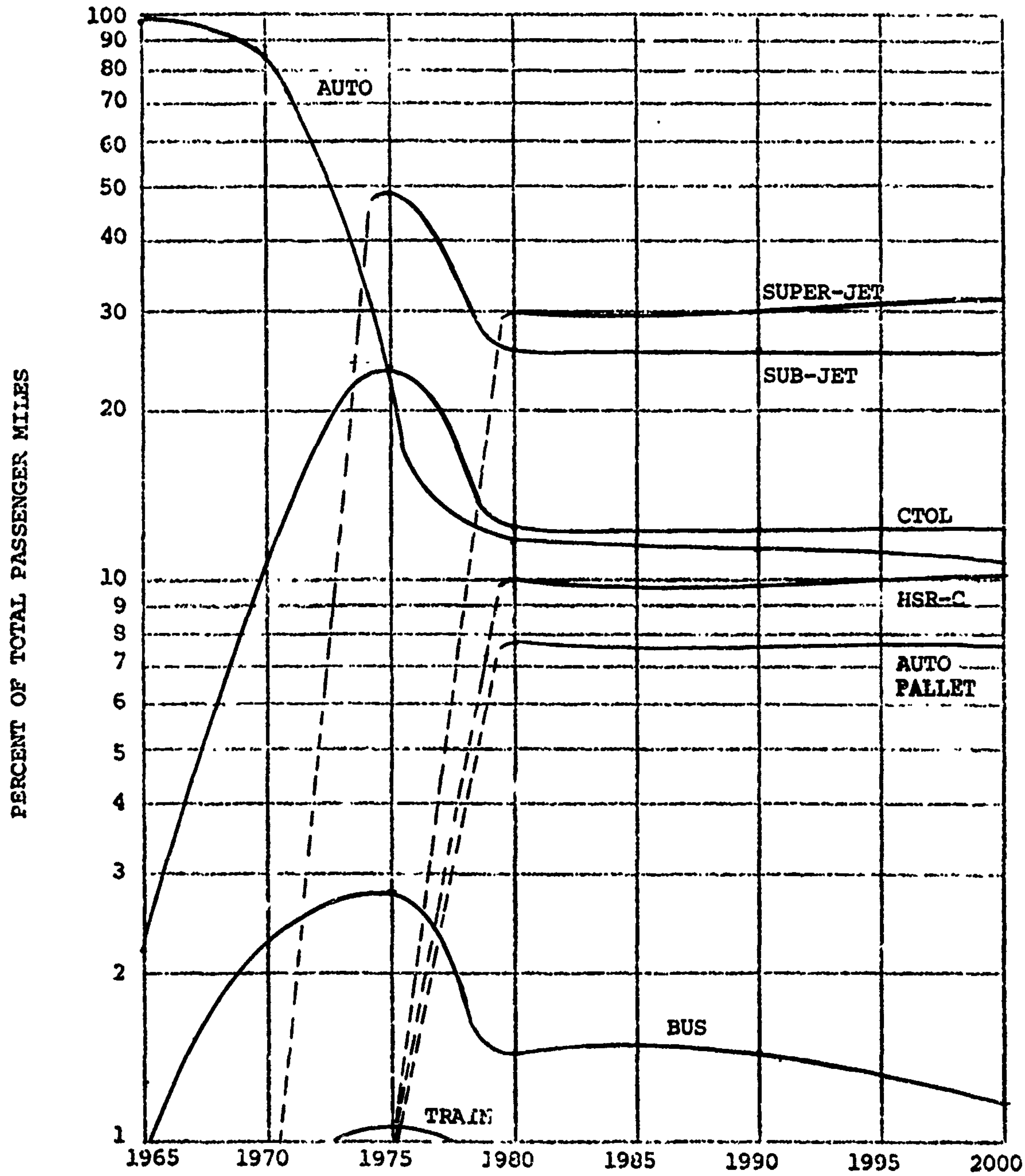
LEGEND

LOCATION: Non-urban

DISTANCE INTERVAL: 1000-3500 miles NO. OF PASSENGERS: 2

AVERAGE DISTANCE : 1400 miles NO. OF PASSENGERS WITH TIME VALUE : 2

FIGURE GG-4
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Non-Urban

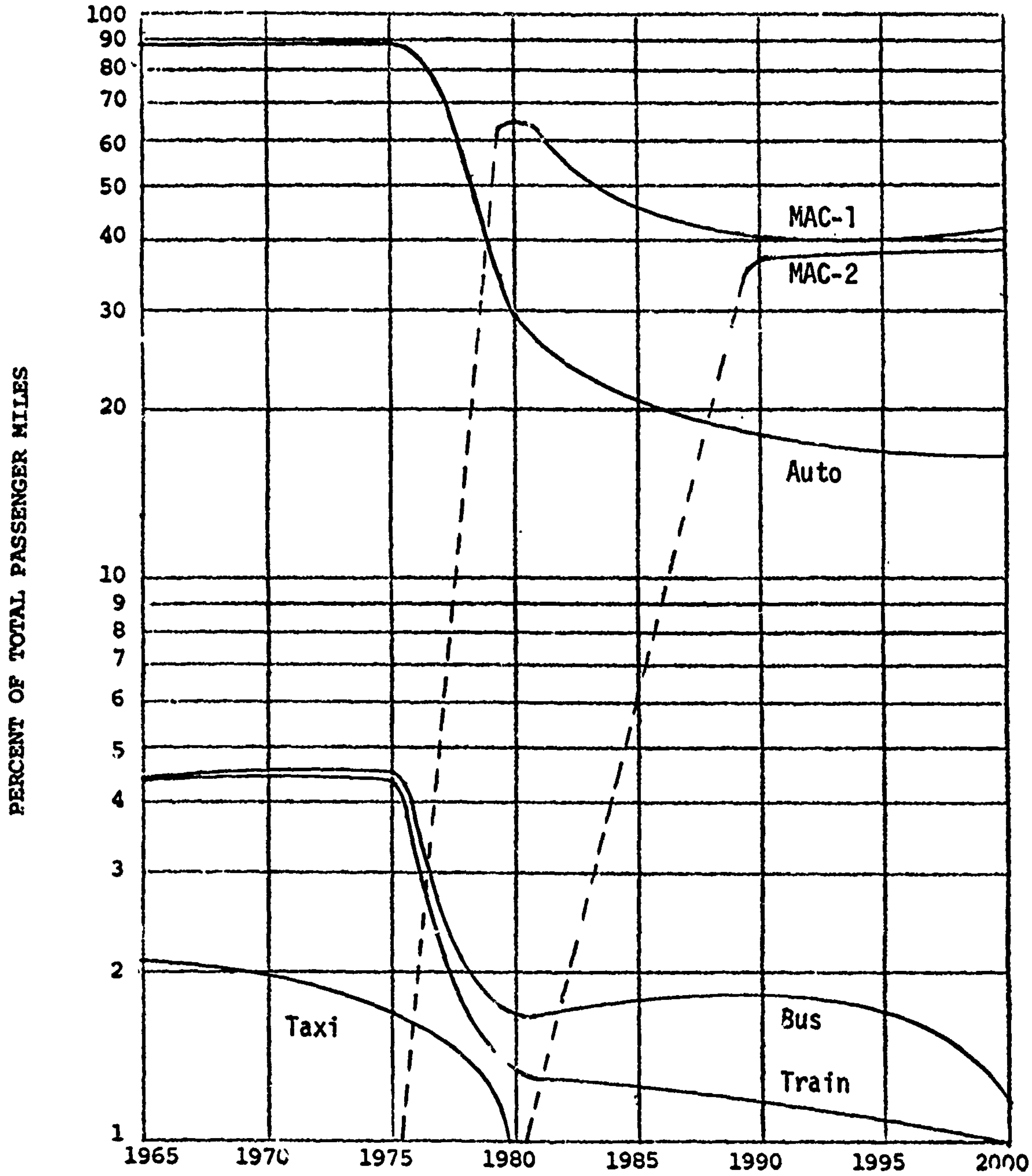
DISTANCE INTERVAL: 100-3500 Miles NO. OF PASSENGERS: 4

AVERAGE DISTANCE : 1400 Miles NO. OF PASSENGERS WITH TIME VALUE : 4

Figure Set II: AA-1 and AA-1a,

Distance Interval 0-2.5 Miles.
Location: Dense Urban (change in velocity and interface time).

FIGURE AA-1
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Dense Urban

DISTANCE INTERVAL: 0-2.5 miles

NO. OF PASSENGERS: 1

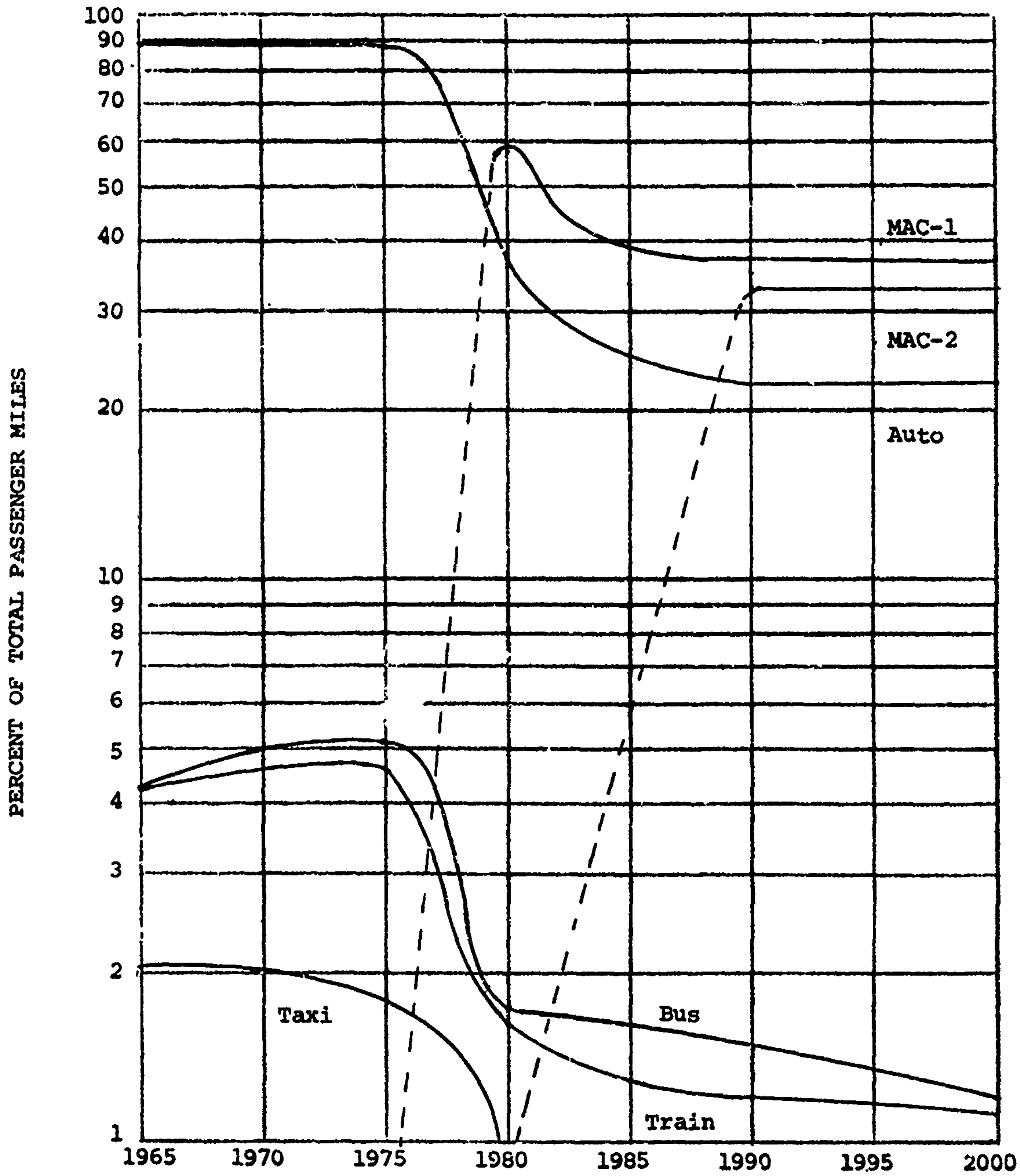
AVERAGE DISTANCE : .75 miles

NO. OF PASSENGERS WITH TIME VALUE : 1

Figure Set III: CD-1, CD-1a, CD-1b, CD-1c.

Distance Interval, 20-50 miles, location non-urban

FIGURE AA-1a
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Dense Urban

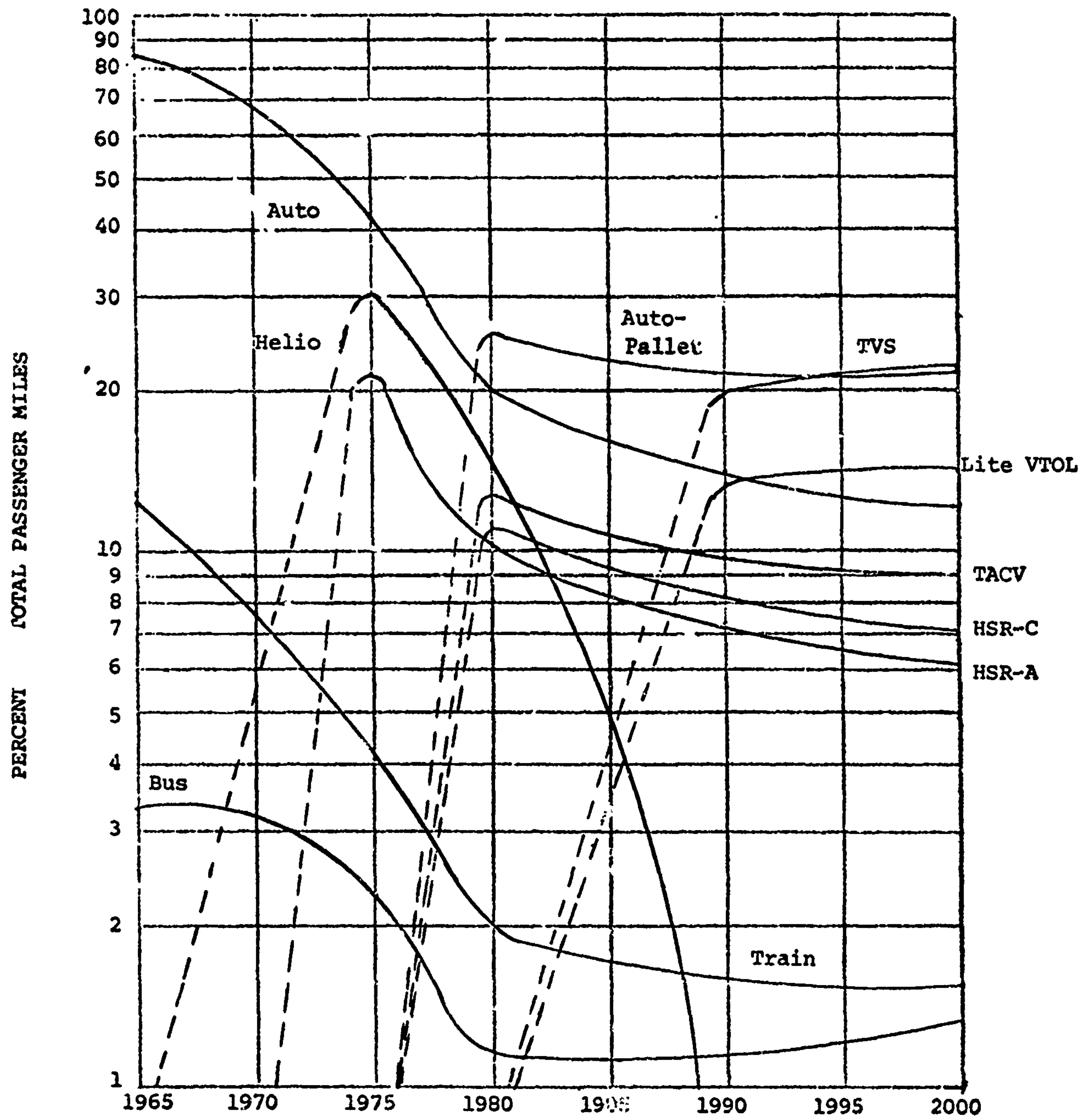
DISTANCE INTERVAL: 0-2.5 miles

NO. OF PASSENGERS: 1

AVERAGE DISTANCE : 75 miles

NO. OF PASSENGERS WITH TIME VALUE : 1

FIGURE CD-1
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Non-Urban

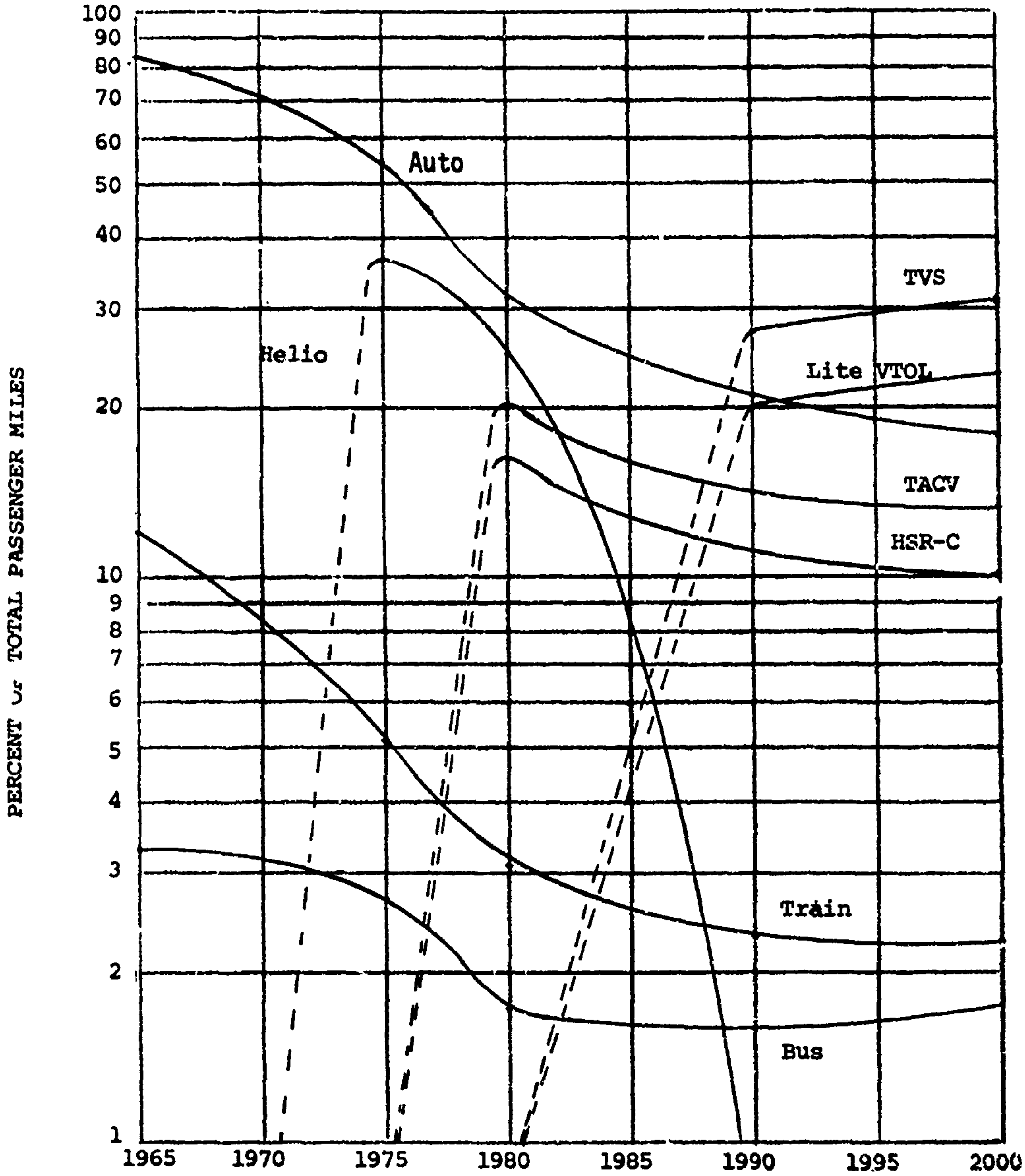
DISTANCE INTERVAL: 20-50 miles

NO. OF PASSENGERS: 1

AVERAGE DISTANCE : 24 miles

NO. OF PASSENGERS WITH TIME VALUE : 1

FIGURE CD-1a
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Non-Urban

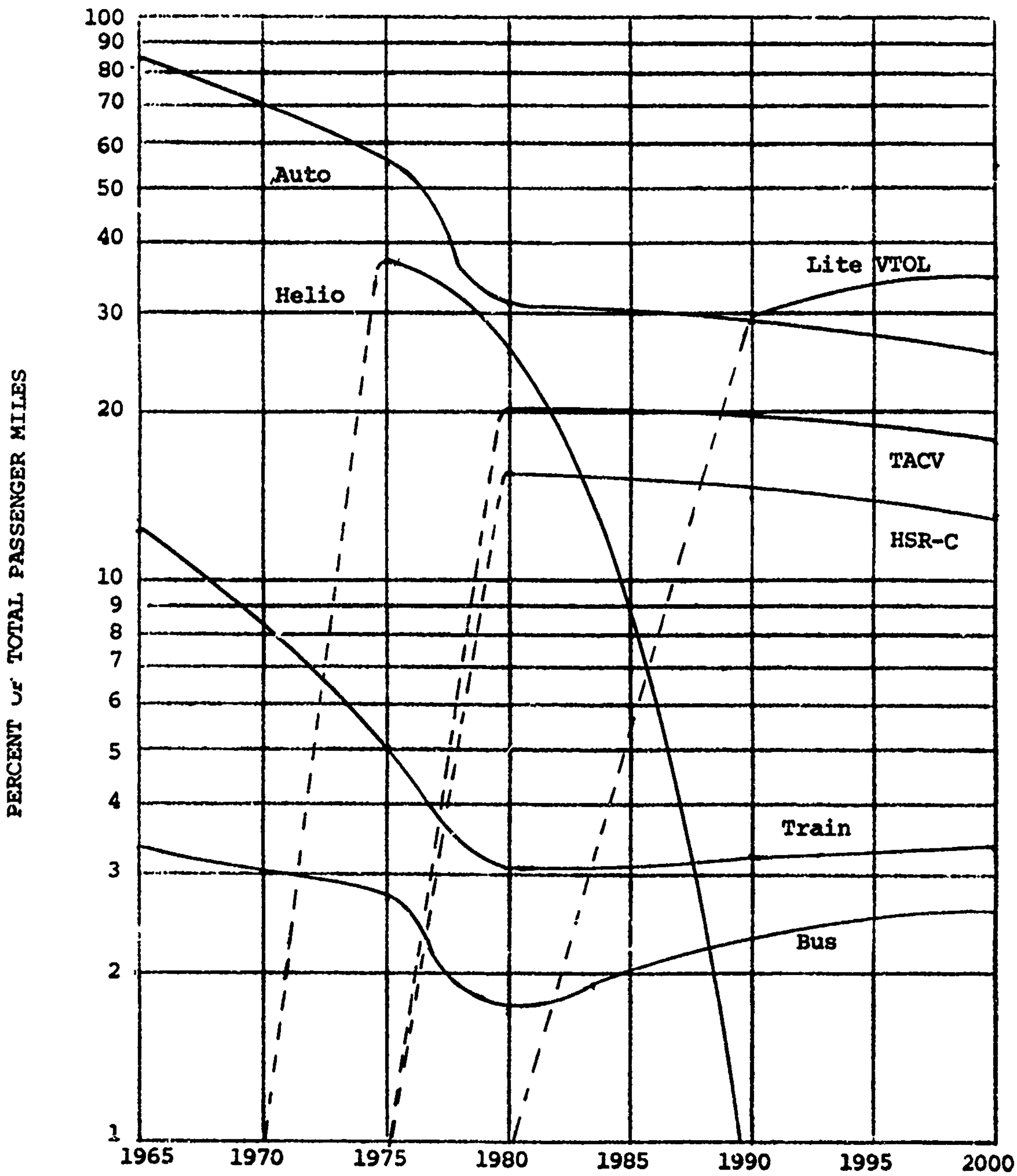
DISTANCE INTERVAL: 20-50 miles

NO. OF PASSENGERS: 1

AVERAGE DISTANCE : 24 miles

NO. OF PASSENGERS
WITH TIME VALUE : 1

FIGURE CD-1b
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



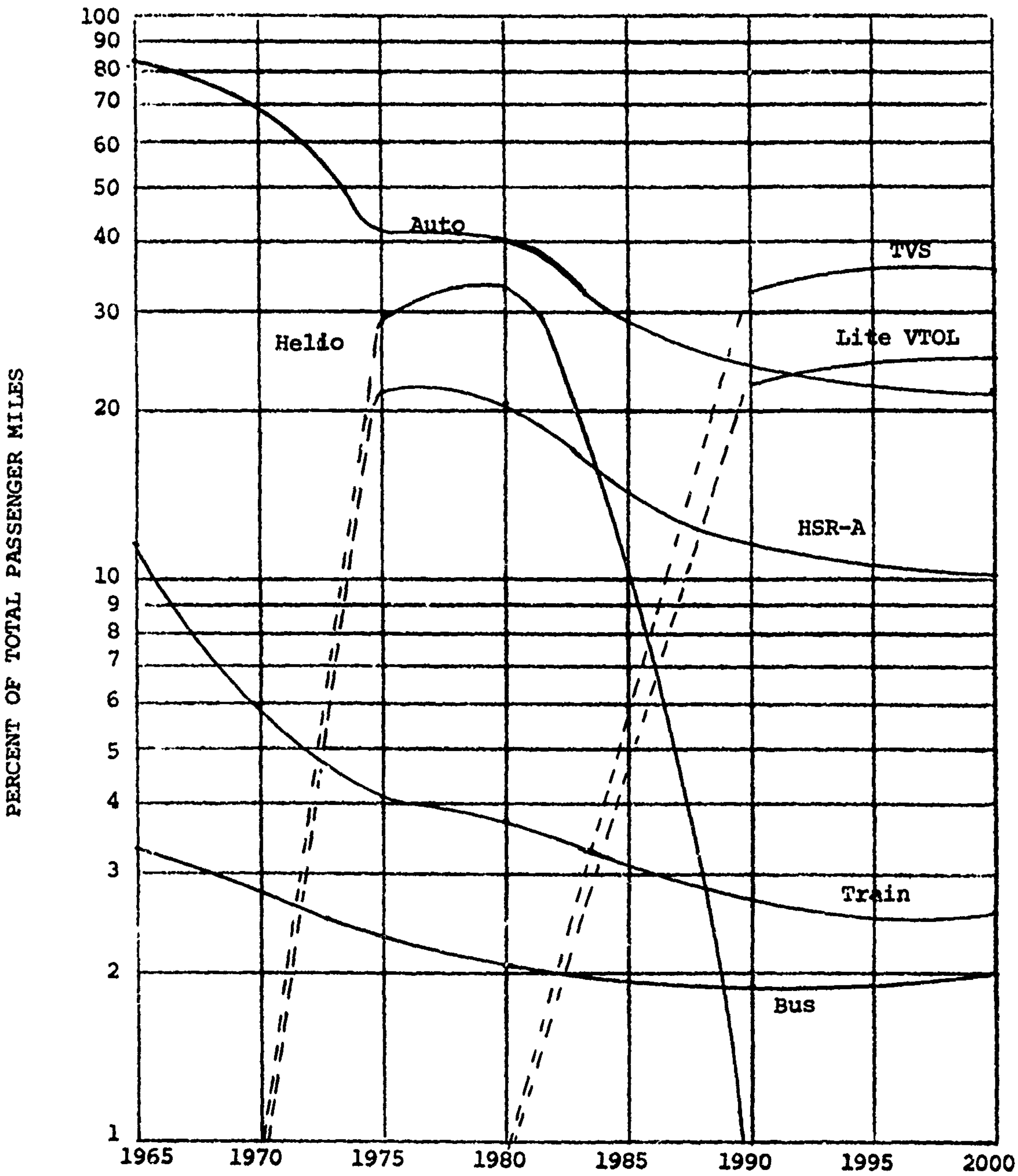
LEGEND

LOCATION: Non-Urban

DISTANCE INTERVAL: 20-50 miles NO. OF PASSENGERS: 1

AVERAGE DISTANCE : 24 miles NO. OF PASSENGERS WITH TIME VALUE : 1

FIGURE CD-1c
PASSENGER MILE MODAL SPLIT
AS FUNCTION OF FORECAST YEAR



LEGEND

LOCATION: Non-Urban

DISTANCE INTERVAL: 20-50 miles

NO. OF PASSENGERS: 1

AVERAGE DISTANCE : 24 miles

NO. OF PASSENGERS WITH TIME VALUE : 1

APPENDIX 1

1.1 Derivation of Cumulative Percentage Population Versus Income Distribution Curve

1.1.1 Background:

The procedure for determining income distribution in future years is dependent on the development of several functions derived from data and forecasts developed by the National Planning Association (NPA) and the Bureau of Census. First, a function is developed for the Lorenz distribution of the cumulative percentage income of consumer units versus the cumulative percentage of consumer units in order of increasing income. Second, a function is developed to describe the growth of the total consumer income for the forecast period of 1960 to the year 2000. Third, a function is developed to describe the growth in the total number of consumer units for the forecast period of 1960 to the year 2000. Fourth, the percentages of the Lorenz function are then converted into actual cumulative unit income and cumulative consumer units for each of the forecast years. Fifth, the derivative of the resulting curve is then used to determine the percentage of consumer unit population applicable to specific income levels.

1.1.2 Assumptions and Methodology:

1.1.2.1 It was assumed that the Lorenz distribution will remain fixed to the year 2000. A 10th degree equation was found to describe the Lorenz curve distribution based on data contained in table 471 of the Statistical Abstract of the U. S. 1968 which shows that this distribution has remained relatively stable since 1947. The 10th degree curve is plotted in figure 1-1 and is described by the

following:

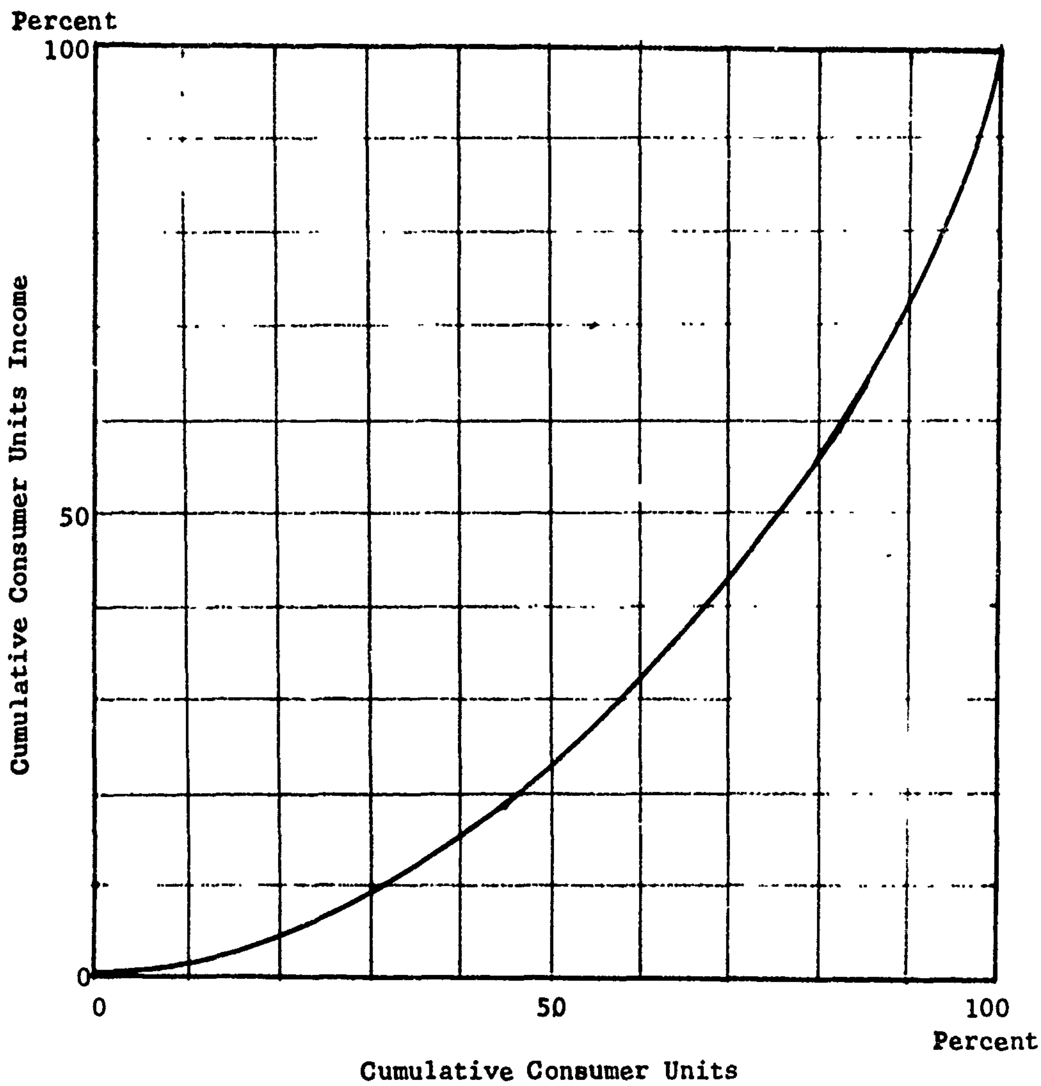
Y = accumulated percentages of consumer units income in order of increasing income.

P = accumulated percentages of population in order of increasing income.

(Eq. 1) $$Y = \sum_{i=0}^{10} c_i P^{a_i}$$

i	c_i	a_i
0	$-9.50108297525 \times 10^{-3}$	0
1	$-1.45305412795 \times 10^{-1}$	1
2	$+7.32367138425 \times 10^{-2}$	2
3	$-8.79111253508 \times 10^{-3}$	3
4	$+6.06492926063 \times 10^{-4}$	4
5	$-2.42471650585 \times 10^{-5}$	5
6	$+5.93887422321 \times 10^{-7}$	6
7	$-9.02763076300 \times 10^{-9}$	7
8	$+8.29358895695 \times 10^{-11}$	8
9	$-4.21216817490 \times 10^{-13}$	9
10	$+9.07284827201 \times 10^{-16}$	10

1.1.2.2 Consumer unit totals and consumer unit income totals for the years 1960, 1966, 1973 and 1980 furnished by the National Planning Association were used to develop growth functions for these variables. Growth functions were also developed for gross national product based on NPA estimates for the period of 1975 to 1990, and for population based on Series C projections of the Bureau of Census. It was found that the growth rate for consumer unit income was the same as for GNP. In both cases GNP is estimated to grow at a rate of 4.6% to 1973 and 4.8% thereafter. In the case of population totals, however, it was



Equation 1: U. S. Lorenz Distribution

Figure 1-1

found that the NPA consumer unit estimates are allowed to increase at a rate of 1.6% per year whereas the Series C projections indicate a growth rate of 1.38% per year. Since it was desired that the results of this procedure be compared to the income distribution for 1960, 1966, 1973 and 1980 derived by NPA, the 1.6% rate based on NPA estimates was used. The four functions are described as follows and are plotted on figures 1-2 and 1-3.

1.1.2.2.1 The following functions estimates the growth in consumer unit income:

if:

CY_n = consumer unit income in year n in 1958 constant dollars

then:

(Eq. 2a) $$CY_n = 353.8(1.046)^{(n-1960)} \qquad n = 1960\text{-}1972$$

(Eq. 2b) $$CY_n = 634.8(1.048)^{(n-1973)} \qquad n = 1973\text{-}2000$$

1.1.2.2.2 The following function estimates the growth in gross national product:

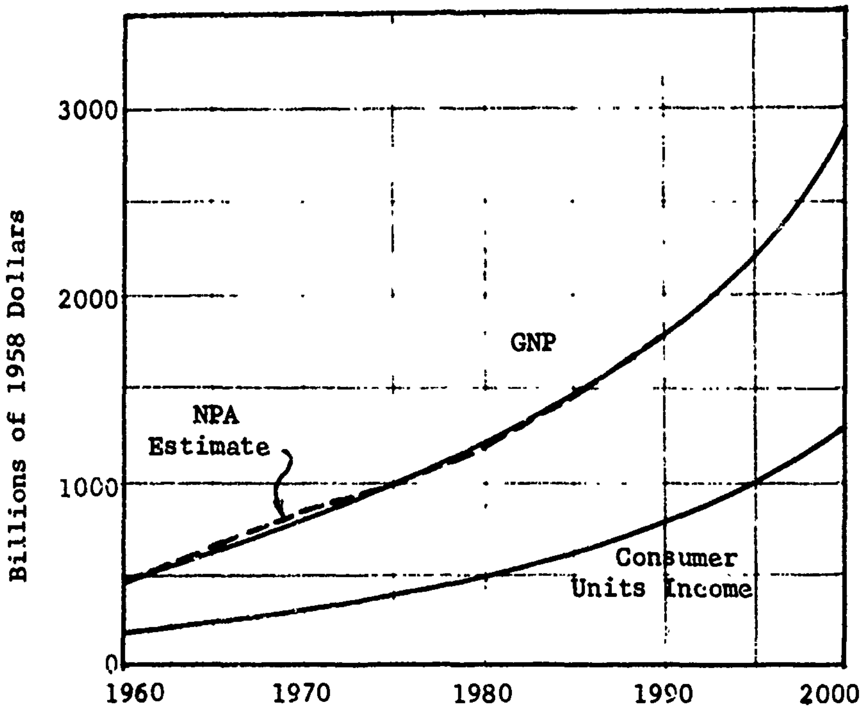
if:

GNP_n = GNP in year n in 1958 constant dollars

then:

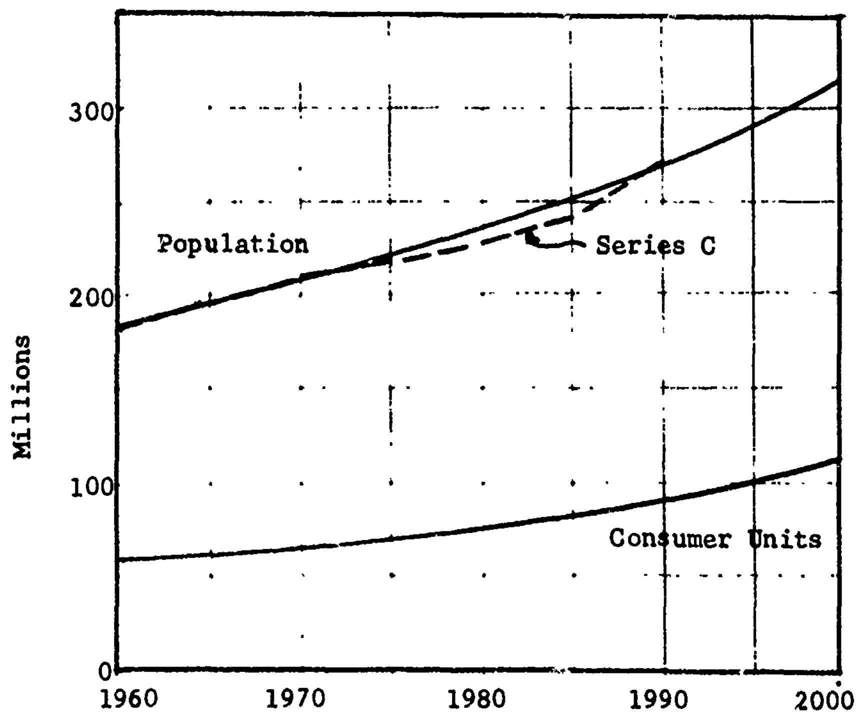
(Eq. 3a) $$GNP_n = 487.7(1.046)^{(n-1960)} \qquad n = 1960\text{-}1972$$

(Eq. 3b) $$GNP_n = 861.5(1.048)^{(n-1973)} \qquad n = 1973\text{-}2000$$



Equations 2 and 3

Figure 1-2



Equations 3 and 4

Figure 1-3

1.1.2.2.3 The following function estimates the growth in consumer units.

if:

CU_n = consumer units in year n

then:

(Eq. 4) $$CU_n = 56.3(1.016)^{(n-1960)} \qquad n = 1960\text{-}2000$$

1.1.2.2.4 This compares with the Series C growth rate function as follows:

if:

P_n = population in year n

then:

(Eq. 5) $$P_n = 180.60(1.0138)^{(n-1960)} \qquad n = 1960\text{-}2000$$

1.1.2.3 The Lorenz distribution described in equation 1 was used to describe distribution in terms of consumer units income and consumer units. These distributions are shown in figure 1-4 and described as follows:

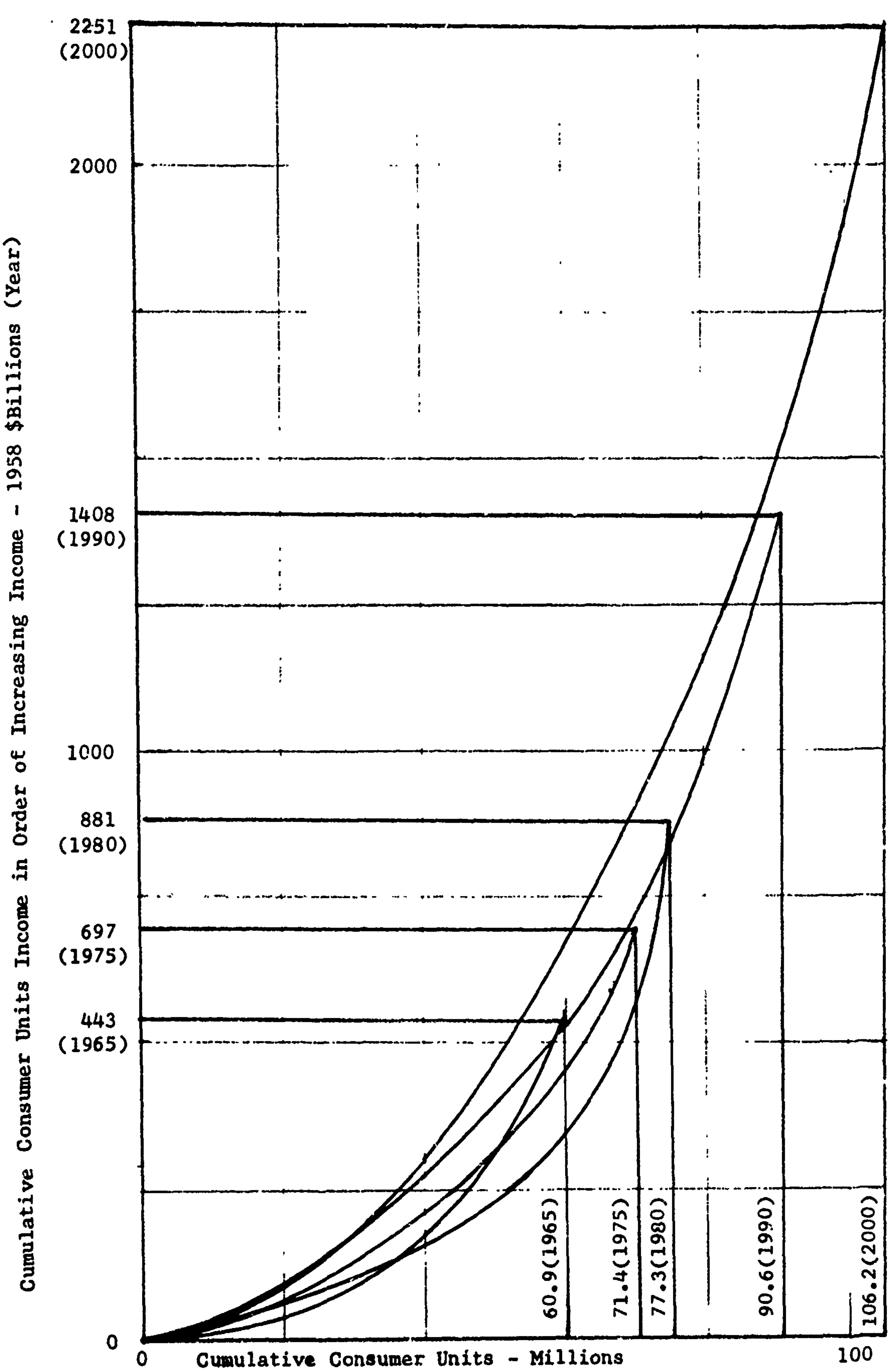
if DY_{jn} = a level j of cumulative income in year n in order of increasing income per unit

DX_{jn} = a level j of cumulative consumer units in year n in order of increasing income

c_i = coefficients described in equation 1 above for i = 0 to 10

i = exponents described in equation 1 above for i = 0 to 10

and CY_n and CU_n = from Eq. 2 and Eq. 3.



Equation 6

Figure 1-4

(Eq. 6) then $DY_{jn} = (CY_n/CU_n)\sum_{i=0}^{10}(c_i)(DX_{jn})^i))$

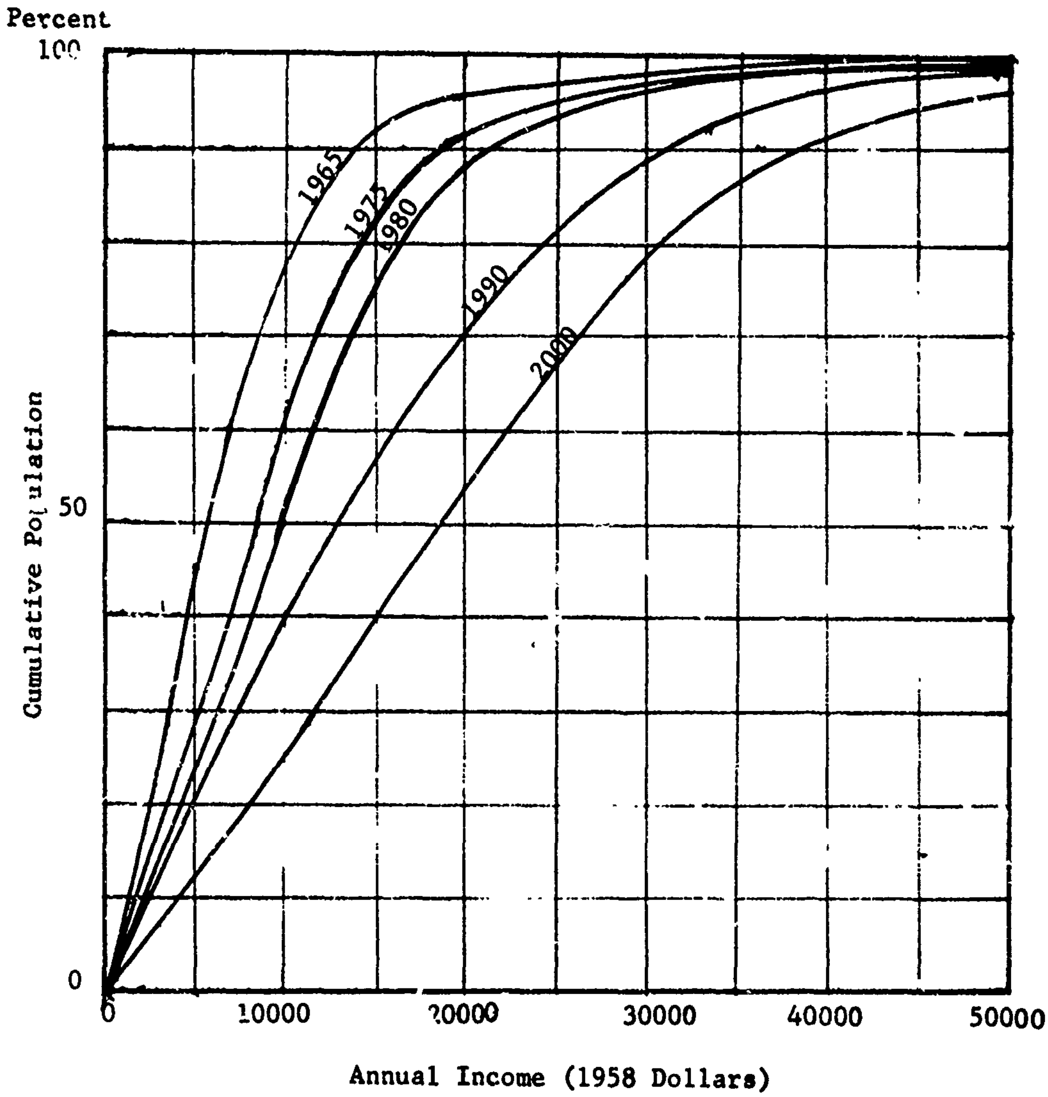
1.1.2.4 The derivations of equation 6 describe the income of an individual at DX_{jn}. The derivative was next allowed to equal various income levels in an increment of $1000 and the number of cumulative income units at each level was noted. Income distribution between any two income levels was represented by the difference in cumulative consumer units at each level. The consumer units were then converted to percentages. The results for 1965, 1975, 1980, 1990 and the year 2000 are plotted in figure 1-5.

1.2 Development of a 1965 U.S. Domestic Passenger Mile Data Table

Table 1-1, "1965 U.S. Domestic Passenger-Mile Data" describes various characteristics of passenger travel in the United States relevant to existing and proposed modes of transportation.

1.2.1 Distribution of passenger-miles by trip length were found as described below. The results are plotted in figure 1-6 which plots percentage cumulative passenger-miles versus distance in order of increasing trip length. The distances are plotted on logarithmic scale.

1.2.1.1 Interurban: Cumulative curves were plotted for passenger-miles versus distance based on data contained in the 1963 and the 1967 Census of Transportation National Travel Survey.



Income Distribution Forecasts

Figure 1-5

TABLE 1-1

1965 U. S. DOMESTIC PASSENGER - MILE DATA

DEPARTMENT OF TRANSPORTATION
THE OFFICE OF THE ASSISTANT SECRETARY
FOR POLICY AND INTERNATIONAL AFFAIRS
APRIL 15,1970

TRIP LENGTH --- ZONE ---	PER CENT OF ALL PASNGR -MILES	PASNGR -MILES (P-M) (1965)	MODE	TYPE OF WAY	TYPE OF CON-TROL	VELO CITY MPH PER HR	MAX P-M PER LANE	RT OF WAY FT	COST PER P-M ($)	TOTAL TRANSP COST $BILNS	SAFETY TOTAL ACCI-DENTS (000)	SAFETY TOTAL DEATHS	SAFETY TOTAL INJU-RIES (000)	SAFETY TOTAL COST $BILN	POLLUTION TOTAL TONS MILNS	POLLUTION TOTAL COST $BILN	NOISE TOTAL COST $BILNS	TOTAL ALL COSTS $BILNS
.00	1.66	26.4	AUTO	ROAD	MANL	10	2900	25	.060	1.58	244.7	631	22.70	.19				1.78
TO	.04	.6	TAXI	ROAD	MANL	15	2900	25	.200	.13	5.9	15	.55	.00				.13
2.50	.06	1.0	BUS	ROAD	MANL	8	6000	25	.050	.05	.9	2	.07	.00				.05
	.06	1.0	TRAIN	RAIL	MANL	16.5	40000	30	.070	.07	.0	1	.10	.00				.07
DENSE			MAC-1	CONVR	AUTO	10.9	8000	6	.175									
URBAN			MAC-2	GUIDE	AUTO	12.3	2500	8	.375									
SUBTOTS	1.82	29.0								1.83	251.5	649	23.42	.20				2.03
.00																		
TO	2.77	44.1	AUTO	ROAD	MANL	20	2900	25	.060	2.65	408.8	1054	37.93	.32				2.97
2.50	.05	.9	TAXI	ROAD	MANL	25	2900	25	.200	.17	8.0	21	.74	.01				.18
	.11	1.7	BUS	ROAD	MANL	15	6000	25	.080	.14	1.4	3	.12	.00				.14
OTHER			DIALBUS	ROAD	MIXD	18	2500	25	.250									
URBAN			PAS	ROAD	MIXD	18	2500	25	.135									
SUBTOTS	2.93	46.7								2.93	418.2	1078	38.79	.33				3.29
.00																		
TO	.98	15.6	AUTO	ROAD	MANL	20	2900	25	.060	.94	144.6	373	13.42	.11				1.05
2.50	.01	.2	BUS	ROAD	MANL	15	6000	25	.030	.01	.2	0	.01	.00				.01
NON URBAN																		
SUBTOTS	.99	15.8								.94	144.8	373	13.43	.11				1.06
TOTALS	5.74	91.5								5.70	814.5	2100	75.64	.64				6.38

TABLE 1-1--Continued

TRIP LENGTH --- ZONE ---	PER CENT OF ALL PASNGR -MILES	PASNGR -MILES (P-M) (1965)	MODE	TYPE OF WAY	TYPE OF CON-TROL	VELO CITY MI PER HR	MAX P-M PER LANE	RT OF WAY FT	COST PER P-M ($)	TOTAL TRANSP COST $BILNS	SAFETY: TOTAL ACCI-DENTS (000)	SAFETY: TOTAL DEATHS	SAFETY: TOTAL INJU-RIES (000)	SAFETY: TOTAL COST $BILN	POLLUTION: TOTAL TONS MILNS	POLLUTION: TOTAL COST $BILN	NOISE: TOTAL COST $BILNS	TOTAL ALL COSTS $BILNS
	29.37	466.8	AUTO	ROAD	MANL	17.2	2900	25	.050	23.34	4327.2	11157	401.45	3.38				26.72
	.16	2.5	TAXI	ROAD	MANL	20	2900	25	.200	.50	23.2	60	2.15	.02				.52
2.50	1.11	17.6	BUS	ROAD	MANL	16	6000	25	.045	.79	14.3	33	1.20	.01				.81
TO	.42	6.6	TRAIN	RAIL	MANL	18.9	40000	30	.040	.26	.2	6	.66	.00				.26
20.00			DIALBUS	ROAD	MIXD	13	2500	25	.040									
			NET 1-2	GUIDE	AUTO	50	10000	8	.070									
URBAN			NET-3	GUIDE	AUTO	50	10000	8	.080									
			FTL-1	GUIDE	AUTO	100	40000	8	.100									
			FTL-2	RAIL	AUTO	100	60000	12	.150									
SUBTOTS	31.06	493.5								24.89	4364.9	11256	405.46	3.41				28.31
2.50																		
TO	5.01	79.7	AUTO	ROAD	MANL	30	2900	25	.050	3.99	738.8	1905	68.54	.58				4.56
20.00	.03	.4	BUS	ROAD	MANL	25	6000	25	.030	.01	.3	1	.03	.00				.01
NON	.02	.3	TRAIN	RAIL	MANL	35	40000	30	.048	.01	.0	0	.03	.00				.01
URBAN																		
SUBTOTS	5.05	80.4								4.01	739.2	1906	68.60	.58				4.59
TOTALS	36.11	573.9								28.90	5104.1	13162	474.06	3.99				32.90
	6.16	97.9	AUTO	ROAD	MANL	35	2900	25	.050	4.89	907.5	2340	84.19	.71				5.60
20.00	.23	3.7	BUS	ROAD	MANL	30	6000	25	.045	.17	3.0	7	.25	.00				.17
TO	.09	1.4	TRAIN	RAIL	MANL	40	40000	30	.040	.06	.0	1	.14	.00				.06
50.00			NET-3	GUIDE	AUTO	50	10000	8	.080									
			FTL-1	GUIDE	AUTO	60	40000	8	.100									
URBAN			FTL-2	RAIL	AUTO	100	60000	12	.150									
SUBTOTS	6.48	103.0								5.12	910.5	2348	84.58	.71				5.83
	1.78	28.3	AUTO	ROAD	MANL	40	2900	25	.050	1.42	262.3	676	24.34	.21				1.62
	.04	.6	BUS	ROAD	MANL	35	6000	25	.030	.02	.5	1	.04	.00				.02
20.00	.14	2.3	TRAIN	RAIL	MANL	45	40000	30	.048	.11	.1	2	.23	.00				.11
TO			NET-3	GUIDE	AUTO	40	10000	8	.080									
50.00			HSR-A	RAIL	MANL	55	12000	30	.118									
			HSR-C	RAIL	MIXD	70	15000	30	.126									
NON			TACV	GUIDE	AUTO	106	12000	20	.134									
URBAN			TVS	RAIL	AUTO	170	10000	30	.150									
			AUTOPALET	RAIL	AUTO	130	54000	30	.080									
			HELICOPTR	AIR	MANL	195	3030		.230									
			LITEVTOL	AIR	MANL	250	200		.077									
SUBTOTS	1.96	31.2								1.54	262.9	680	24.61	.21				1.75
TOTALS	8.44	134.2								6.66	1173.4	3028	109.19	.92				7.58

TRIP LENGTH --- ZONE ---	PER CENT OF ALL PASNGR -MILES	PASNGR -MILES (P-M) (1965)	MODE	TYPE OF WAY	TYPE OF CON-TROL	VELOCITY MI PER HR	MAX P-M PER LANE	RT OF WAY FT	COST PER P-M ($)	TOTAL TRANSP COST $BILNS	SAFETY TOTAL ACCI-DENTS (000)	SAFETY TOTAL DEATHS	SAFETY TOTAL INJU-RIES (000)	SAFETY TOTAL COST $BILN	POLLUTION TOTAL TONS MILNS	POLLUTION TOTAL COST $BILN	NOISE TOTAL COST $BILNS	TOTAL ALL COSTS $BILNS
	14.36	278.3	AUTO	ROAD	MANL	45	2900	25	.040	9.13	2116.3	5456	196.34	1.66				10.79
	.31	4.9	BUS	ROAD	MANL	44.1	6000	25	.030	.15	4.0	9	.33	.00				.15
	.39	6.2	TRAIN	RAIL	MANL	41	40000	30	.050	.31	.2	6.	.62	.00				.31
	.16	2.6	CTOL	AIR	MANL	47.4	2000		.070	.18	.0	8	.01	.00				.18
			SHIP	SEA	MANL	1.6			.010									
50.00			HSR-A	RAIL	MANL	111	12000	30	.118									
TO			HSR-C	RAIL	MIXD	158	15000	30	.126									
200.00			TACV	GUIDE	AUTO	258	12000	20	.134									
			TVS	RAIL	AUTO	350	10000	30	.150									
NON			AUTOPALET	RAIL	AUTO	130	54000	30	.080									
URBAN			HELICOPTR	AIR	MANL	100	3000		.181									
			LITEPLANE	AIR	MANL	200	200		.077									
			3LEVPLANE	AIR	MANL	210	1000		.125									
			STOL	AIR	MANL	260	2000		.190									
			VTOL	AIR	MANL	455	4000		.289									
			LITEVTOL	AIR	MANL	250	200		.077									
SUBTOTS	15.22	242.0								9.77	2120.5	5479	197.30	1.66				11.43
TOTALS	15.22	242.0								9.77	2120.5	5479	197.30	1.66				11.43
	9.43	149.9	AUTO	ROAD	MANL	50	2900	25	.040	6.00	1389.6	3583	128.91	1.09				7.08
	.48	7.5	BUS	ROAD	MANL	43.5	6000	25	.030	.23	6.2	14	.52	.01				.23
	.44	7.0	TRAIN	RAIL	MANL	46.6	40000	30	.050	.35	.2	6	.70	.00				.35
	.60	9.6	CTOL	AIR	MANL	236	2000		.060	.58	.0	29	.03	.00				.58
200.00			SHIP	SEA	MANL	1.6			.010									
TO			HSR-C	RAIL	MIXD	158	15000	30	.126									
500.00			TACV	GUIDE	AUTO	258	12000	20	.134									
			TVS	RAIL	AUTO	350	10000	30	.150									
NON			AUTOPALET	RAIL	AUTO	130	54000	30	.080									
URBAN			HELICOPTR	AIR	MANL	287	3000		.162									
			LITEPLANE	AIR	MANL	200	200		.077									
			3LEVPLANE	AIR	MANL	210	1000		.070									
			STOL	AIR	MANL	260	2000		.078									
			VTOL	AIR	MANL	455	4000		.150									
SUBTOTS	10.95	174.1								7.15	1395.9	3635	130.16	1.10				8.25
TOTALS	10.95	174.1								7.15	1395.9	3635	130.16	1.10				8.25

TABLE 1-1--Continued

TRIP LENGTH --- ZONE ---	PER CENT OF ALL PASNGR -MILES	PASNGR -MILES (B-M) (1965)	MODE	TYPE OF WAY	TYPE OF CON-TROL	VELO CITY MI PER HR	MAX P-M PER LANE	RT OF WAY FT	COST PER P-M ($)	TOTAL TRANSP COST $BILNS	SAFETY: TOTAL ACCI-DENTS (000)	SAFETY: TOTAL DEATHS	SAFETY: TOTAL INJU-RIES (000)	SAFETY: TOTAL COST $BILN	POLLUTION: TOTAL TONS MILNS	POLLUTION: TOTAL COST $BILN	NOISE: TOTAL COST $BILNS	TOTAL ALL COSTS $BILNS
	7.19	114.3	AUTO	ROAD	MANL	55	2900	25	.040	4.57	1059.6	2732	98.30	.83				5.40
	.25	3.9	BUS	ROAD	MANL	45	6000	25	.030	.12	3.2	7	.27	.00				.12
	.04	.6	TRAIN	RAIL	MANL	40.2	40000	30	.050	.03	.0	1	.06	.00				.03
	.91	14.5	CTOL	AIR	MANL	250	2000		.060	.87	.0	43	.04	.00				.87
500.00			HSR-C	RAIL	MIXD	158	15000	30	.126									
TO			TACV	GUIDE	AUTO	258	12000	20	.134									
1000.00			TVS	RAIL	AUTO	350	10000	30	.150									
			AUTOPALET	RAIL	AUTO	130	54000	30	.080									
NON			LITEPLANE	AIR	MANL	200	200		.077									
URBAN			3LEVPLANE	AIR	MANL	210	1000		.070									
			STOL	AIR	MANL	260	2000		.078									
			VTOL	AIR	MANL	455	4000		.150									
			SUBSONJET	AIR	MANL	410	10000		.047									
SUBTOTS	8.39	133.3								5.59	1062.7	2783	98.67	.84				6.43
TOTALS	8.39	133.3								5.59	1062.7	2783	98.67	.84				6.43
	12.68	201.5	AUTO	ROAD	MANL	55	2900	25	.040	8.06	1867.9	4816	173.29	1.46				9.52
	.39	6.2	BUS	ROAD	MANL	41	6000	25	.030	.19	5.0	12	.42	.00				.19
	.08	1.2	TRAIN	RAIL	MANL	50.2	40000	30	.050	.06	.0	1	.12	.00				.06
	1.98	31.4	CTOL	AIR	MANL	33.8	2000		.060	1.88	.1	94	.09	.01				1.89
			HSR-C	RAIL	MIXD	158	15000	30	.126									
1000.00			TACV	GUIDE	AUTO	258	12000	20	.134									
TO			TVS	RAIL	AUTO	360	10000	30	.150									
3500.00			AUTOPALET	RAIL	AUTO	130	54000	30	.080									
			LITEPLANE	AIR	MANL	200	200		.077									
NON			3LEVPLANE	AIR	MANL	210	1000		.070									
URBAN			STOL	AIR	MANL	[illegible]	2000		.078									
			VTOL	AIR	MANL	455	4000		.150									
			SUBSONJET	AIR	MANL	475	10000		.047									
			SUPSONJET	AIR	MANL	1170	4000		.047									
SUBTOTS	15.13	240.3								10.19	1873.0	4923	173.92	1.47				11.66
TOTALS	15.13	240.3								10.19	1873.0	4923	173.92	1.47				11.66
GTOTALS	100.00	1589.3								73.99	13544.1	35106	1258.9	10.64				84.63

A curve midway between the two 1963 and 1967 curves was plotted and used to represent 1965 distribution of cumulative passenger-miles for each of the modes.

1.2.1.2 Urban: The total number of trips for all modes in each trip length block reflects the distributions reported by Stanford Research Institute on page 59 of document Final Report 1, Future Urban Transportation Systems, March 1968. Differences between modes were then developed based on average trip lengths reported by Meyer-Kain-Wohl in The Urban Transportation Problem, 1965.

1.2.2 The total passenger-miles for each mode in 1965 was then distributed in accordance with the above distributions. These totals were obtained as follows:

1.2.2.1 Interurban: Passenger-miles for all modes are reported in Table 800 of the Statistical Abstract of the United States.

1.2.2.2 Urban: Different sources and procedures were used for each mode as follows:

1.2.2.2.1 Automobile passenger-miles are based on the inter-urban-urban vehicle mile totals reported in Table VM-1 of the 1965 Highway Statistics Handbook. On advice of Bureau of Public Roads personnel, a ratio of 2.3 passengers per vehicle

in interurban travel and 1.7 passengers per vehicle in urban travel was used to convert vehicle-miles to passenger-miles. This provided a passenger-mile total for urban areas and confirmed the values previously used for interurban auto travel.

1.2.2.2.2 Bus and train transit passenger totals are reported for 1965 in the 1968 Transit Fact Book. The bus and transit passenger-mile distributions described above were converted to percentage passengers at each distance by dividing passenger-miles by distance. These percentages were applied to the actual bus and train passenger totals to determine passengers at each distance. These were then multiplied by the distances to arrive at passenger-mile totals.

1.2.3 Taxi totals were developed by extrapolating the number of passenger trips reported in the Tri-State area to the national level and multiplying this by the average trip distance for taxis. This data is reported in a document entitled Regional Profile, Who Rides Taxis published by the Tri-State Commission, February 1969.

1.2.4 Transportation Costs.

1.2.4.1 Existing Modes: Gross national product totals for the passenger transportation sector as reported by the Transportation Association of America were used as approximate control totals to insure that

totals developed from unit costs were reasonably accurate. In the case of bus and train, these totals were simply divided by passenger-miles at each trip distance to arrive at unit costs. In the case of air, it was assumed that unit costs were equal to fares and fares reported by CAB were used. Automobile costs are based on Bureau of Public Roads estimated costs per vehicle-mile divided by the occupancy ratios reported above. For all these modes minor adjustments were made to reflect cost differences by distance blocks. These were based mostly on judgment.

1.2.4.2 New Modes: Costs for new types of passenger systems are available from current internal studies of the Department of Transportation and NASA. These systems continue to be under study and the costs reported on Table 1-1 are those which are currently reported.

1.2.4.3 Pollution and Noise Cost: In-house efforts to arrive at a cost of pollution and noise per unit of passenger-mile are not completed. A very preliminary effort indicates that in 1965, pollution costs were on the order of about $6 billion. This value, however, should be used with caution.

1.2.4.4 Safety Costs and Other Safety Data: The Statistical Abstract of the United States, the National Safety Council reports and the Transportation Association of America reports were used as sources to develop all safety data shown on the chart.

1.2.5 All Other Data.

A large number of sources were used to find entries for average velocities, right-of-way width and capacity per lane. For example, in the case of interurban bus, train and plane, weighted average of city to city trip times were developed from trip time schedules. All velocities shown are the average block speed velocities for the trip length block.

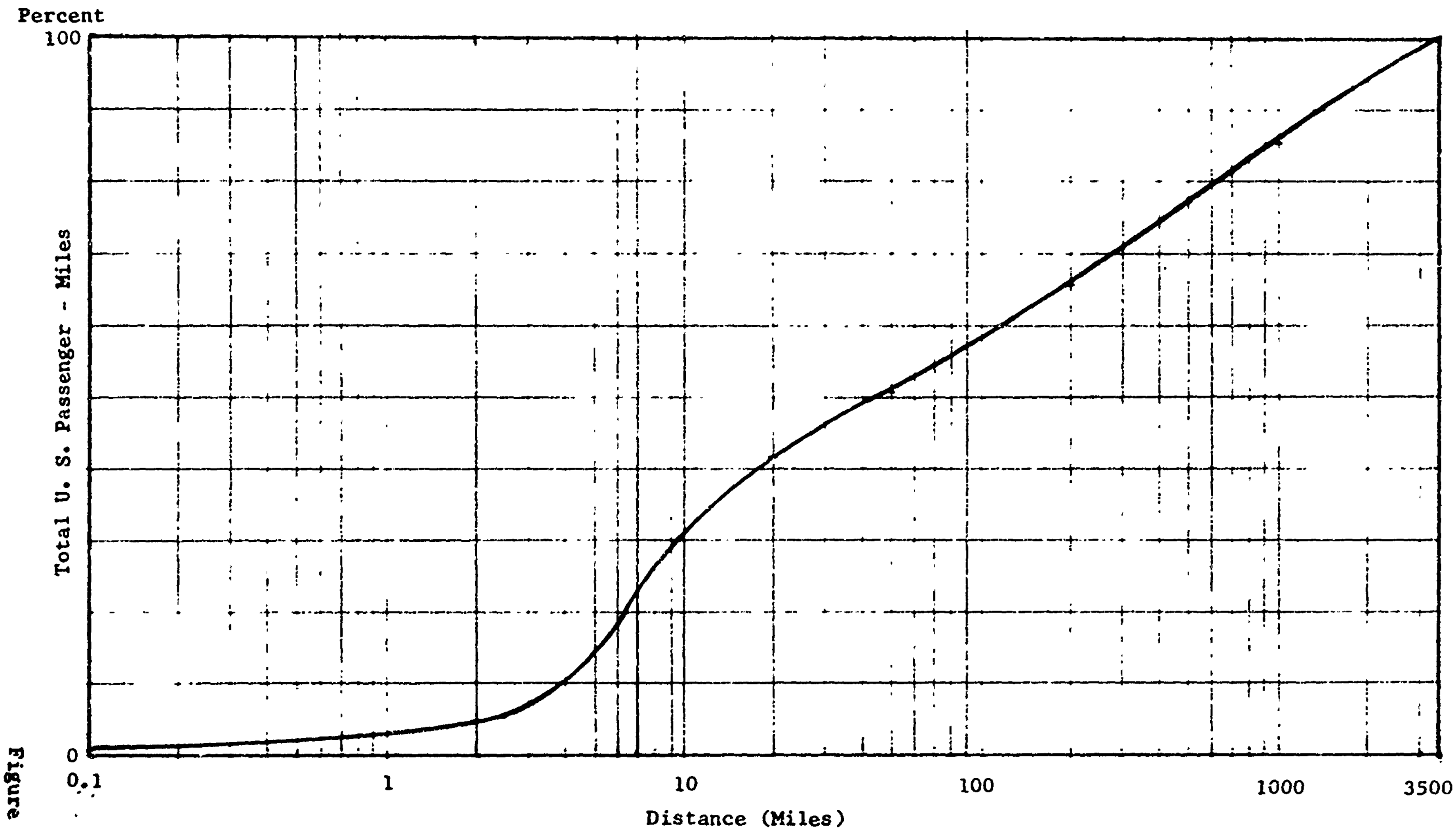
1.2.6 Procedure for Determining the Number of Passenger-Miles Trips at any Distance.

1.2.6.1 The number of passenger-miles at a given distance is represented by the slope of the tangent to the curve at that distance for the curve shown in figure 1-6. A method was developed to approximate this curve mathematically. Dividing the passenger-miles by the size of each distance block produces a linear function. The fact that this function describes a constant slope for each block was considered unsatisfactory. A procedure was then developed to allow the slopes to vary continuously

TABLE 1-14

1965 PERCENTAGE DISTRIBUTION OF PASSENGER-MILES BY GROUP SIZE

Distance Block-Mi	Percent of All Pass-Mi	Billion Pass-Mi	Mode	Percent of Block Pass-Mi	Mode Pass-Mi	1 Person Group		2 Persons Group		3 Persons Group		4+ Persons Group	
						% of Block	% of Group	% of Block	% of Group	% of Block	% of Group	% of Block	% of Group
0-2.5 High Density	1.83	29.04	Auto	90.91	26.40	68.18	89.44	16.46	95.29	3.82	95.98	2.45	97.45
			Bus	3.44	1.00	3.23	4.24	.18	1.02	.03	.87	+	.14
			Train	3.44	1.00	3.23	4.24	.18	1.02	.03	.86	+	.14
			Taxi	2.21	0.64	1.59	2.08	.46	2.67	.10	2.38	.06	2.27
				100.00	29.04	76.23	100.00	17.28	100.00	3.98	100.00	2.51	100.00
0-2.5 Urban	2.94	46.66	Auto	94.51	44.10	70.88	94.84	17.11	93.65	3.97	92.15	2.55	94.96
			Bus	3.64	1.70	2.52	3.38	.77	4.23	.26	6.01	.09	3.25
			Taxi	1.85	0.86	1.33	1.78	[illegible]	2.12	.08	1.84	.05	1.79
				100.00	46.66	74.73	100.00	18.27	100.00	4.31	100.00	2.69	100.00
0-2.5 Non-Urban	.99	15.80	Auto	98.73	15.60	74.05	98.48	17.87	99.47	4.15	99.42	2.66	99.99
			Bus	1.27	.20	1.15	1.52	.10	.53	.02	.58	0	.01
				100.00	15.80	75.20	100.00	17.97	100.00	4.17	100.00	2.66	100.00
2.5-20 Urban	31.05	493.50	Auto	94.59	466.80	70.94	93.66	17.12	97.29	3.98	97.19	2.55	99.43
			Bus	3.57	17.60	3.23	4.26	.27	1.53	.07	1.66	.00	.04
			Train	1.34	6.60	1.21	1.60	.10	.58	.03	.62	.00	.02
			Taxi	.50	2.50	.36	.48	.11	.60	.02	.53	.01	.51
				100.00	493.50	75.74	100.00	17.60	100.00	4.10	100.00	2.56	100.00
2.5-20 Non-Urban	5.06	80.40	Auto	99.13	79.70	55.51	98.72	20.82	99.46	12.89	99.87	9.91	99.82
			Bus	.50	.40	.42	.73	.06	.31	.01	.08	.01	.10
			Train	.37	.30	.31	.55	.05	.23	.01	.05	0	.08
				100.00	80.40	56.24	100.00	20.93	100.00	12.91	100.00	9.92	100.00
20-50 Urban	6.48	103.00	Auto	95.05	97.90	71.29	93.88	17.20	98.55	3.99	98.77	2.57	99.81
			Bus	3.59	3.70	3.37	4.44	.18	1.05	.04	.89	+	.14
			Train	1.36	1.40	1.28	1.68	.07	.40	.01	.34	+	.05
				100.00	103.00	75.94	100.00	17.45	100.00	4.04	100.00	2.57	100.00
20-50 Non-Urban	1.96	31.20	Auto	90.71	28.30	34.47	83.74	21.77	91.77	16.14	97.99	16.33	98.32
			Bus	1.92	.60	1.38	3.36	.40	1.70	.08	.42	.06	.35
			Train	7.37	2.30	5.31	12.90	1.55	6.53	.29	1.59	.22	1.33
				100.00	31.20	41.16	100.00	23.72	100.00	18.51	100.00	16.61	100.00
50-200 Non-Urban	15.23	242.00	Auto	94.34	228.30	18.68	85.60	25.85	93.90	17.73	97.62	32.08	98.74
			Bus	2.02	4.90	1.26	5.79	.54	1.96	.12	.67	.10	.31
			Train	2.56	6.20	1.18	5.41	.88	3.20	.24	1.35	.26	.79
			Plane	1.08	2.60	.70	3.20	.26	.94	.07	.36	.05	.16
				100.00	242.00	21.82	100.00	27.53	100.00	18.16	100.00	32.49	100.00
200-500 Non-Urban	10.95	174.10	Auto	86.10	149.90	17.05	67.62	23.59	85.91	16.19	94.30	29.27	97.05
			Bus	4.37	7.60	2.73	10.81	1.16	4.23	.26	1.53	.22	.72
			Train	4.02	7.00	1.85	7.35	1.38	5.02	.39	2.25	.40	1.33
			Plane	5.51	9.60	3.58	14.22	1.33	4.84	.33	1.92	.27	.90
				100.00	174.10	25.21	100.00	27.46	100.00	17.17	100.00	30.16	100.00
500-1000 Non-Urban	8.39	133.30	Auto	85.75	114.30	16.97	65.10	23.50	86.86	16.12	94.87	29.16	97.58
			Bus	2.93	3.90	1.83	7.00	.78	2.88	.17	1.03	.15	.49
			Train	0.45	.60	.21	.80	.15	.57	.04	.25	.05	.15
			Plane	10.87	14.50	7.07	27.10	2.62	9.69	.65	3.85	.53	1.78
				100.00	133.30	26.08	100.00	27.05	100.00	16.98	100.00	29.89	100.00
1000-3500 Non-Urban	15.12	240.30	Auto	83.85	201.50	16.60	61.64	22.98	85.15	15.76	94.11	28.51	97.21
			Bus	2.53	6.20	1.61	5.98	.69	2.54	.15	.92	.13	.44
			Train	.50	1.20	.23	.35	.17	.64	.05	.29	.05	.17
			Plane	13.07	31.40	8.50	31.53	3.15	11.67	.78	4.68	.64	2.18
				100.00	240.30	26.94	100.00	26.99	100.00	16.74	100.00	29.33	100.00
	100.00	1589.30			1589.30								



Distribution of Passenger - Miles

by Trip Length

Figure 1-6

without changing the total passenger-miles reported for each distance block. A series of non zero slope lines are defined whose ordinate at any distance measures the total passenger-miles applicable to that distance.

1.2.6.2 Since the figure 1-6 function is in percentages of passenger miles, distributions were then developed for the years 1975, 1980, 1990 and 2000 by converting cumulative percentages to actual passenger-miles based on the values for total passenger-miles produced by Equation 7 (see paragraph 1.4). These curves are shown in Figure 1-7.

1.3 Development of Trip Distributions by Size of Groups.

1.3.1 Table 1-1a describes the percentage distribution of passenger-miles by group size. This data was developed as described below.

1.3.2 Interurban: Percentage distributions are based on data from the 1967 Census of Transportation National Travel Survey. Trips were converted to passenger-miles based on average distances for each distance block. These distances were derived by comparing person mile and trip mile summaries contained in the same report. Group sizes were used to determine the number of passenger-miles for each trip.

1.3.3 The group size split for urban travel was determined by manipulating group size data for the cities of Boston,

1965 PERCENTAGE DISTRIBUTION OF PASSENGER-MILES BY GROUP SIZE

Distance Block-Mi	Percent of All Pass-Mi	Billion Pass-Mi	Mode	Percent of Block Pass-Mi	Mode Pass-Mi	1 Person Group % of Block	1 Person Group % of Group	2 Persons Group % of Block	2 Persons Group % of Group	3 Persons Group % of Block	3 Persons Group % of Group	4+ Persons Group % of Block	4+ Persons Group % of Group
0-2.5 High Density	1.83	29.04	Auto	90.91	26.40	68.18	89.44	16.46	95	3.82	95.98	2.45	97.45
			Bus	3.44	1.00	3.23	4.24	.18	1.	.03	.87	+	.14
			Train	3.44	1.00	3.23	4.24	.18	1.02	.03	.86	+	.14
			Taxi	2.21	0.64	1.59	2.08	.46	2.67	.10	2.38	.06	2.27
				100.00	29.04	76.23	100.00	17.28	100.00	3.98	100.00	2.51	100.00
0-2.5 Urban	2.94	46.66	Auto	94.51	44.10	70.88	94.84	17.11	93.65	3.97	92.15	2.55	94.96
			Bus	3.64	1.70	2.52	3.38	.77	4.23	.26	6.01	.09	3.25
			Taxi	1.85	0.86	1.33	1.78	.39	2.12	.08	1.84	.05	1.79
				100.00	46.66	74.73	100.00	17.27	100.00	4.31	100.00	2.69	100.00
0-2.5 Non-Urban	.99	15.80	Auto	98.73	15.60	74.05	98.48	17.87	99.47	4.15	99.42	2.66	99.99
			Bus	1.27	.20	1.15	1.52	.10	.53	.02	.58	0	.01
				100.00	15.80	75.20	100.00	17.97	100.00	4.17	100.00	2.66	100.00
2.5-20 Urban	31.05	493.50	Auto	94.59	466.80	70.94	93.66	17.12	97.29	3.98	97.19	2.55	99.43
			Bus	3.57	17.60	3.23	4.26	.27	1.53	.07	1.66	.00	.04
			Train	1.34	6.60	1.21	1.60	.10	.58	.03	.62	.00	.02
			Taxi	.50	2.50	.36	.48	.11	.60	.02	.53	.01	.51
				100.00	493.50	75.74	100.00	17.60	100.00	4.10	100.00	2.56	100.00
2.5-20 Non-Urban	5.06	80.40	Auto	99.13	79.70	55.51	98.72	20.82	99.46	12.89	99.87	9.91	99.82
			Bus	.50	.40	.42	.73	.06	.31	.01	.08	.01	.10
			Train	.37	.30	.31	.55	.05	.23	.01	.05	0	.08
				100.00	80.40	56.24	100.00	20.93	100.00	12.91	100.00	9.92	100.00
20-50 Urban	6.48	103.00	Auto	95.05	97.90	71.29	93.88	17.20	98.55	3.99	98.77	2.57	99.81
			Bus	3.59	3.70	3.37	4.44	.18	1.05	.04	.89	+	.14
			Train	1.36	1.40	1.28	1.68	.07	.40	.01	.34	+	.05
				100.00	103.00	75.94	100.00	17.45	100.00	4.04	100.00	2.57	100.00
20-50 Non-Urban	1.96	31.20	Auto	90.71	28.30	34.47	83.74	21.77	91.77	18.14	97.99	16.33	98.32
			Bus	1.92	.60	1.38	3.36	.40	1.70	.08	.42	.06	.35
			Train	7.37	2.30	5.31	12.90	1.55	6.53	.29	1.59	.22	1.33
				100.00	31.20	41.16	100.00	23.72	100.00	18.51	100.00	16.61	100.00
50-200 Non-Urban	15.23	242.00	Auto	94.34	228.30	18.68	85.60	25.85	93.90	17.73	97.62	32.08	98.74
			Bus	2.02	4.90	1.26	5.79	.54	1.96	.12	.67	.10	.31
			Train	2.56	6.20	1.18	5.41	.88	3.20	.24	1.35	.26	.79
			Plane	1.08	2.60	.70	3.20	.26	.94	.07	.36	.05	.16
				100.00	242.00	21.82	100.00	27.53	100.00	18.16	100.00	32.49	100.00
200-500 Non-Urban	10.95	174.10	Auto	86.10	149.90	17.05	67.62	23.59	85.91	16.19	94.30	29.27	97.05
			Bus	4.37	7.60	2.73	10.81	1.16	4.23	.26	1.53	.22	.72
			Train	4.02	7.00	1.85	7.35	1.38	5.02	.39	2.25	.40	1.33
			Plane	5.51	9.60	3.58	14.22	1.33	4.84	.33	1.92	.27	.90
				100.00	174.10	25.21	100.00	27.46	100.00	17.17	100.00	30.16	100.00
500-1000 Non-Urban	8.39	133.30	Auto	85.75	114.30	16.97	65.10	23.50	86.86	16.12	94.87	29.16	97.58
			Bus	2.93	3.90	1.83	7.00	.78	2.88	.17	1.03	.15	.49
			Train	0.45	.60	.21	.80	.15	.57	.04	.25	.05	.15
			Plane	10.87	14.50	7.07	27.10	2.62	9.69	.65	3.85	.53	1.78
				100.00	133.30	26.08	100.00	27.05	100.00	16.98	100.00	29.89	100.00
1000-3500 Non-Urban	15.12	240.30	Auto	83.85	201.50	16.60	61.64	22.98	85.15	15.76	94.11	28.51	97.21
			Bus	2.58	6.20	1.61	5.98	.69	2.54	.15	.92	.13	.44
			Train	.50	1.20	.23	.85	.17	.64	.05	.29	.05	.17
			Plane	13.07	31.40	8.50	31.53	3.15	11.67	.78	4.68	.64	2.18
				100.00	240.30	26.94	100.00	26.99	100.00	16.74	100.00	29.33	100.00
	100.00	1589.30			1589.30								

Table 1-1a

Milwaukee, and Springfield, Mass. reported by Wilbur Smith & Associates in the report Patterns of Car Ownership, Trip Generation, and Trip Sharing in Urbanized Areas. Tables 5.4, 5.5 and 5.6 provide total trip travel by auto school bus and transit by group size. Data from page 188 of The Urban Transportation Problem by Meyer-Kain-Wohl, 1965 was used to establish bus trip distance distribution.

Taxi group sizes are based on a report by the Tri-State Transportation Committee entitled Regional Profile--Who Rides Taxis, February 1969. This source provided a group size distribution and an average distance from which passenger mile data could be developed.

1.4 Methodology for Forecasting Future Travel U. S. Passenger Mile Totals.

1.4.1 A series of regressions was made using 1946 to 1966 total U. S. passenger-miles as the dependent variable and various combinations of population, civilian employment and gross national product as the independent variables. Regressions were made for both the totals and the differences. The independent variables finally chosen were civilian employment and the ratio of GNP to population. Using absolute totals produced an r^2 value of 0.959. Using the yearly differences produced an r^2 value of 0.38. The yearly difference equation was used to extrapolate to the 1965 to 2000 period.

if:

DPM_n = yearly change in passenger miles in year n, 1947 -1966

DCE_n = yearly change in civilian employment in year n, 1947-1966

DG_n = yearly change in gross national product in year n, 1947-1966

DP_n = yearly change in population in year n, 1947-1966

then:

(Eq. 7) $$DP_n = (35.4565-1.7359(DCE_n)+.1629(DG_n)/(DP))10^9$$

1.4.2 A function was next developed to describe forecasts of future civilian employment which have been developed by the National Planning Association for the period of 1975 to 1990. It was assumed that the values produced by this function would also apply to the year 2000.

if:

CE_n = civilian employment in year n

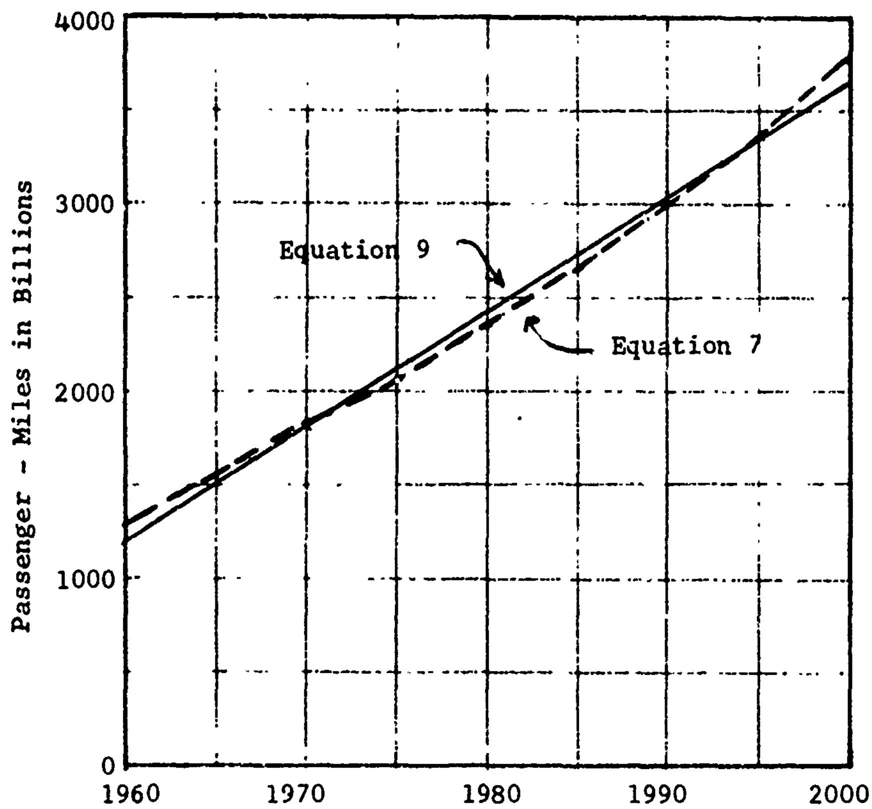
then:

(Eq. 8) $$CE_n = 65.778 \text{ X } 10^6(1.018)^{(n-1960)} \quad n = 1969 \text{ to } 2000$$

1.4.3 The Equations 3, 5 and 8 were used to develop the inputs for Equation 7. The Equation 7 results were converted to total passenger-miles and are shown in figure I-7. It will be noted that for the period of 1965 to 2000, these values vary almost linearly and may be described by a linear function. The linear fit analysis produced an r^2 value of .9935 and the following equation:

if: PM_n = passenger-miles travelled in year n

(Eq. 9) then: $$PM_n = (-118,267+60.9514(n))10^9 \quad n = 1965 \text{ to } 2000$$



Equations 7 and 9

Figure 1-7

1.4.4 It was also determined that there exists a reasonable linear fit when passenger-miles are determined as a function of population. The linear fit analysis produced an r^2 value of .994 and the following equation 10 described below. In figure 1-8 are plotted the passenger-mile vs. population relationships using Equations 7, 9 and 10:

if:

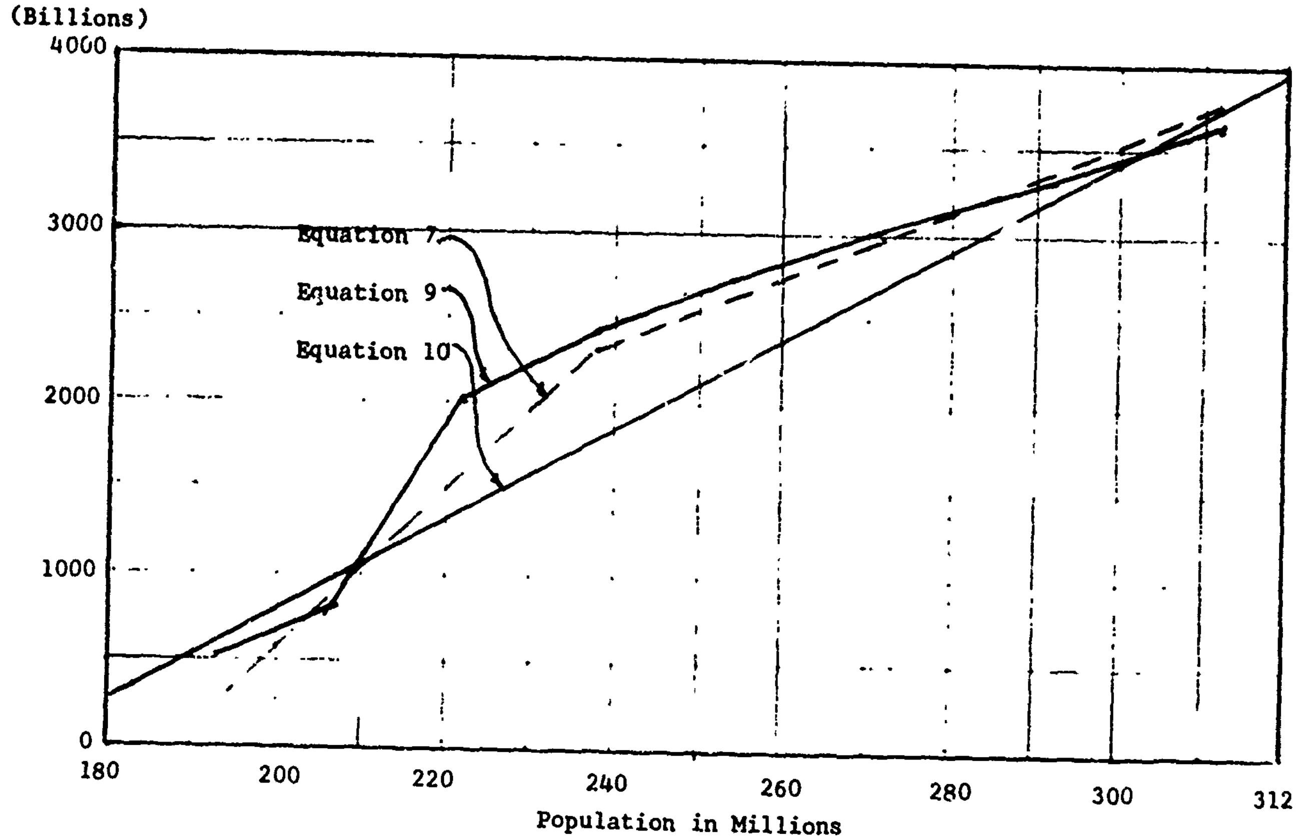
PM = passenger-miles in billions

and:

P = population in millions

then:

(Eq. 10) $PM = -2017.6 + 18.41856P$ for $P = 180\text{-}320$



Passenger - Miles as a Function

of Population

Figure 1-8

ADDENDUM TO ENDIX 1

Definitions Applicable to Passenger-Mile Transportation Table 1-1

1. Passenger-miles:

Definition: One passenger traveling one mile.

Source: Automobile vehicle-miles for rural roads and urban streets shown in Table VM-1, December 1966 of 1965 Highway Statistics Book. Ratio of 1.7 passengers per vehicle in urban streets and 2.3 passengers per vehicle in rural roads used to convert to passenger miles. Rural total confirmed by Table 802, 1968 Statistical Abstract of U.S. Ratios provided by Mr. French of BPR. Other modes treated similarly or estimated.

2. Trip Length:

Definition: Line haul distance in statute miles between origin and destination on the right-of-way.

Source: Intercity distributions largely based on 1967 Census of Transportation data. Urban distances distribution based on miscellaneous data found in SRI report to UMTA entitled "Future Urban Transportation Systems," Final Report 1, March, 1968.

3. Trip Densities

Definition: The density and frequency of travel typical of the area for which a new mode is to be designed. The origin and destination blocks describe the range of origins and destinations occurring per

square mile per hour. The line haul block describes the range of passenger miles per lane per hour.

Source: Table 3 of SRI report referenced above in paragraph 2, where applicable. When not applicable, estimates were made by extrapolation of this data.

4. Geographic Area:

Definition: Transportation needs for three environments: rural, urban and intercity. Further division is made by trip density patterns. The split between urban and non-urban identifies the data as provided by sources named in paragraphs 1,2,3. These sources, however, do not specifically define these terms. For purposes of the study, a non-urban split between intercity and rural is an estimate based on the ratio of rural population to total population (i.e., 50,000,000 to 200,000,000) applied to non-urban travel.

Source: Office of Systems Requirements, Plans and Information

5. Percent of Total Passenger-miles:

Definition: Portion of total passenger miles measured in percent applicable to a specific trip length or set of trip lengths as a function of geographic area and as a function of modes. All percentage columns total to 100. Sub-totals within blocks are equal to the total for the block.

Source: In some cases percentages are computed from passenger-miles, in other cases, passenger miles are computed from percentages depending on the data as derived from the sources listed in paragraphs 1 through 4.

6. <u>Ways</u>:

<u>Definition</u>: The natural or artificially constructed environment required to facilitate the movement of vehicles or product from point-to-point.

<u>Source</u>: Office of Systems Requirements, Plans and Information

7. <u>Control</u>:

<u>Definition</u>: The use of electronic devices to provide information to steer vehicles, regulate their headways, schedule their movements or other purposes as required to permit automated direction of all or part of a vehicular trip.

8. <u>Passenger-miles per Lane per Hour</u>:

<u>Definition</u>: The maximum number of passenger miles that can be generated on one lane or path in one hour without causing a congestive queue and reduction in capacity.

<u>Sources</u>: Highway capacity manual, Meyer, Kain and Wohl's "The Urban Transportation Problems," airline data, and various volumes of the "Study in New Systems of Urban Transportation" produced by the UMTA in 1968.

9. <u>Average Cost per Passenger-mile</u>:

<u>Definition</u>: The annual total of annualized capital cost, annual maintenance costs and annual operating costs of a system divided by the total number of annual passenger-miles for the system.

Sources: Automobile costs are based on BPR estimates of costs per vehicle mile adjusted for passenger-miles in accordance with ratios described in paragraph 1 above and validated to insure a total for all transportation consistent with GNP estimates for transportation. Bus, rail and airline costs are based on data from the Northeast Corridor, Transportation Project reports, the NASA, OART, Mission Analysis Division reports and miscellaneous industry reports. Totals are consistent with GNP data developed by the Transportation Association of America.

10. Average Velocity:

Definition: The average velocity (door-to-door) from origin to destination when the named mode is the mode used for the line haul.

Sources: Office of Systems Requirements, Plans and Information estimates of velocities for average conditions in the described area taking into consideration both the block speed for line haul, the time in interface segments of the trip, and peak hour conditions.

11. Pollution Costs:

Definition: Costs generated by a transportation mode as a consequence of the pollutants that are produced during operations of the system.

Source: HEW sources have estimated that the total annual cost of pollution is $11 billion. UMTA New Systems Study by General Research, Volume 1, page 87 reports total pollution and auto pollution in tons.

Based on this data, Office of Systems Requirements, Plans and Information has estimated tonnage and pollution costs per billion passenger miles for the auto. Tons and costs for other systems were estimated by extrapolation giving due consideration to power systems and passengers per vehicle.

12. Safety Costs:

Definition: The sum of the estimated cost of injuries, administrative insurance costs, and property damage. They do not include public costs, damages awarded in excess of direct cost, indirect costs to employers, etc.

Sources: U.S. Statistical Abstracts and data developed by National Safety Council and TAA.

APPENDIX 2

APPENDIX 2

2.0 General

This appendix contains two products, Table 2-1 and Chart 2-1. Table 2-1 is the 1965 Commodity-Ton Mile Data Table and Chart 2-1 is a supplement to Table 2-1 defining the commodity group classes and the value assigned to each commodity group class used in developing Table 2-1. The information was prepared by Peat, Marwick and Mitchell (Washington Office) for the Office of the Assistant Secretary for Policy and International Affairs, Department of Transportation.

Preceding Table 2-1 are definitions and Chart 2-1 which provide explanations of the information contained within Table 2-1.

2.1 Definitions Applicable to 1965 Commodity Ton-Mile Data Table*

2.1.1 Percent of Total Ton-Miles

Definition: Portion of total ton-miles measured in percent applicable to line entry or entries. All columns total to 100. Sub-totals within blocks are equal to total for the block.

Source: A variety of data development techniques were used to develop either percentages of ton-miles distributions or actual ton-miles based on the data source documents listed in the Bibliography and selected control totals.

---

*Figures in the parentheses refer to source documents as numbered in the report's bibliography.

2.1.2 Commodity Class

Definition: A grouping of the Standard Transportation Commodity Code (32) freight designations was made into three commodity classes (bulk, break bulk, and liquid). The criteria for grouping commodities into classes are as follows:

Class	Definition
Bulk	Small commodities not handled discretely (i.e., grain, etc.) or large items handled as one item per carload or truckload (tanks, cranes, etc.)
Break Bulk	Commodities discretely handled usually in packaged, crated, or other containerized form.
Liquid	Chemicals, petroleums and other liquid products existing naturally in the liquid physical state.

2.1.3 Commodity Value

Definitions: A Grouping of the Standard Transportation Commodity Code (32) freight designations was made into three value classes (low, medium, high). The criteria for value classes are as follows:

Class	Criteria
Low	Between 0 and $200 per ton
Medium	$200 - $1,000 value per ton
High	Greater than $1,000 per ton

2.1.4 Ton Miles

Definition: One tone of freight transported one mile.

Source:

Rail: A control total of 709 billion ton-miles was derived from (35), (39). Detailed commodity data from 1% Carload Waybill Survey (13) were adjusted to the national totals for ton-miles and percentages of rail ton-miles by commodity group were determined.

Truck: A control total of 140 billion ton-miles for Regulated truck was determined from (35), (39), (1). A control total of 269.218 billion ton-miles for non-regulated truck was determined from (35), (39), (1), (17) and the addition of 50 billion ton-miles of local private truck travel based on (15). Data for ICC regulated Class I motor carriers (14) provides tonnage data by commodity code. This together with Census data (37) of commodity movements permitted estimates of both regulated and non-regulated truck ton-miles distribution by commodity groups which were adjusted to the control totals.

Water: A control total of 476.457 billion ton-miles were derived from (35), (36). Commodity data in tons and ton-miles are available from the same source.

Pipe Line: A control total of 306 billion ton-miles was derived from (35) and (27) Data is available from the same sources.

Air: A control total of 1.563 billion ton-miles was derived from (35) and (16). Data was derived from (35) and (22).

2.1.5 Trip-Length

Definition: Line haul distance in statute miles between origin and destination on the right of way.

Rail: Trip length characteristics of commodity groups travelling by rail were determined based on Census data (37).

Truck: Distributions were determined using both Census data (37) and Tri State data (7). Trip length distributions were adjusted to correlate with calculated average trip length.

Water: Trip length distribution was taken from Census data (37) and modified to match average trip lengths derived from Corps of Engineers data (36).

Pipe Line: Rail distribution for liquid commodities was used as an approximation with adjustments to match average trip lengths for oil.

Air: Distributions are derived from Census data (37).

2.1.6 Price-Cents per Ton-Mile

Definition: Fare for transporting one tone of freight one mile.

Source:

Rail: Price of rail freight travel by commodity group and trip length was determined by calculating average revenue per ton-mile for each group from the 1% Waybill Survey (13) estimating the average class of commodities in each commodity group, developing curves of freight rate (cents/ton-mile) vs. trip length (miles) as a function of class rates and rail tariffs (13) and finally adjusting rates in each trip length and commodity group cell such that revenue control totals were maintained.

Truck: As in the rail mode, price charges as a function of trip length were determined by deriving average revenues per ton-miles for each commodity group (13) utilizing the freight tariffs for average class of commodity and trip length range (28) and adjusting to yield revenues derived by using average values. Private truck travel average rates were estimated at 1 cent less per ton-mile than regulated carriers rates for intercity travel. This was compatible with Transportation Association of America (TAA) assumptions in calculating estimate of the Nation's freight bill (35). Local truck rates were determined by dividing ton-miles into revenue for local trucks (35) and using representative class rate curves as a measure of rate variation versus distance.

Water: Average costs data (19) was used as an acceptable average price. Average shipping prices for each commodity group were estimated from differentials in average price available for corresponding rail transported commodities and adjusted to waterborne commerce average. The rate difference in each group as a fraction of trip length were again estimated utilizing a first approximation average price vs. distance curve (based on costs and average trip lengths for travel by internal, Great Lakes and coastwise shipping) and adjusting the resulting prices to match revenues derived from average prices per ton-mile and average trip lengths.

Pipe Line: A first approximation rate per ton-mile vs. distance curve was plotted from representative oil pipe line company revenues and line lengths reported by ICC (34). Prices for shipment in each trip length range were adjusted to match the average price determined from TAA (35).

2.1.7 Total Revenues

Definition: The product of price and ton-miles.

Source: See Source discussions in paragraph 2.1.6 for each mode.

2.1.8 Rail

Definition: Conventional rail, unit trains, trailer and container on flat car, services purchased by freight forwarders.

2.1.9 Regulated Motor Carrier

Definition: Intercity, local and freight forwarder purchased services on regulated motor vehicles.

2.1.10 Private Motor Carrier

Definition: Intercity, local and freight forwarder purchased services utilizing private and contract non-regulated motor vehicles.

2.1.11 Water

Definition: Local, internal, lakewise, coastwise shipping for the contiguous, domestic United States utilizing water-borne vessels.

.1.12 Pipe Line

Definition: All shipments utilizing pipe lines.

2.1.13 Air

Definition: All shipments utilizing commercial air-borne vehicles.

2.1.14 New Modes

Definition: New modes of travel are incorporated into the freight table at applicable trip length ranges for comparison with existing modal data. New modes or operating technologies included in the table are:

- Slurry pipe lines,
- Capsule pipe lines,
- Large diameter, automatic pipe lines,

- Coaxial trains,
- Trailer truck trains,
- Boeing 747, Lockheed-500,
- Aeron 340,
- "Guppy"-enlarged fuselage jet aircraft, and
- Roll on-roll off ships

2.2 Distribution of Major Commodity Groups by Class and Value Utilized in Preparation of 1965 Commodity Ton-Miles Data Table 2-1

2.2.1 The class and value designations shown on Chart 2-1 which follows were determined by comparing definitions for these terms with a listing of products of each input-output section. This comparison process went down to the detail of five and sometimes six digit level of Standard Industrial Classifications. Value divisions are based on the 1963 Census of Manufacturers, from which weights and values for the three-, four-, and five-digit industries which comprise each sector have been developed to the extent Census coverage has allowed.

2.2.2 Commodity Groups Class and Value Chart 2-1, see Page 2-9.

		Class	Value
*A	Group 01 - Farm products	B	L
	Group 08 - Forest products	BB	L
	Group 09 - Fresh fish and other marine products	B	L
	Group 10 - Metallic ores	B	L
	Group 11 - Coal	B	L
	Group 13 - Crude petroleum, natural gas, and natural gasoline	L	L
	Group 14 - Nonmetallic minerals, except fuels	B	L
	Group 19 - Ordnance and accessories	BB	H
*B	Group 20 - Food and kindred products	BB	M
	Group 21 - Tobacco products	BB	H
	Group 22 - Basic textiles	BB	H
	Group 23 - Apparel and other finished textile products, including knit	BB	H
	Group 24 - Lumber and wood products, except furniture	BB	L
	Group 25 - Furniture and fixtures	BB	M
	Group 26 - Pulp, paper and allied products	BB	M
	Group 27 - Printed matter	BB	M
*C	Group 28 - Chemicals and allied products	BB	M
*D	Group 29 - Petroleum and coal products	L	L
	Group 30 - Rubber and miscellaneous plastics products	BB	M
	Group 31 - Leather and leather products	BB	H
*E	Group 32 - Stone, clay, glass, and concrete products.	BB	L
	Group 33 - Primary metal products	BB	M
	Group 34 - Fabricated metal products, except ordnance machinery, and transportation equipment	BB	M
*F	Group 35 - Machinery, except electrical	B	H
	Group 36 - Electrical machinery, equipment and supplies	BB	H
*G	Group 37 - Transportation equipment	BB	H
	Group 38 - Instruments, photographic and optical goods, watches and clocks	BB	H
	Group 39 - Miscellaneous products of manufacturing	BB	H
	Group 40 - Waste and scrap materials	B	L

	Class	Value
*A - Except 01121, 01193, 012, 013	BB	M
*B - Except 2026 Milk	L	L
*C - Except 2812-3, and 50% (2814, 5, 8, 9, 287)	L	L
*D - Except 50% (295, 299)	BB	L
*E - Except 3273	B	H
*F - Except 35313, 3533, 3535, 3537, 3552	BB	H
*G - Except 37112-3, 37151, 37211, 37213, 37323, 37411, 37421 thru 4, 37911	B	H

B - Bulk　　H - High
BB - Break Bulk　　M - Medium
L - Liquid　　L - Low

TRIP LENGTH–TON–MILE–COMMODITY DATA

Percent of total ton-miles	Trip Length	Percent of total ton-miles	Comm. class	Percent of total ton-miles	Value level
0 03	0-2 5	0	B		L
					M
					H
		02	BB	0 002	L
				01	M
				01	H
		01	L	.01	L
					M
					H
2 91	2 5-20	20	B	.15	L
					M
				05	H
		1.60	BB	.14	L
				1 01	M
				45	H
		1.10	L	1.10	L
					M
					H
7 88	20-50	1.36	B	1 28	L
					M
				08	H
		3 43	BB	60	L
				2.11	M
				72	H
		3 10	L	3.10	L
					M
					H
20 63	50-200	3.95	B	3 64	L
					M
				.31	H
		8 02	BB	1 44	L
				5.07	M
				1.51	H
		8 66	L	8.66	L
					M
					H
19 48	200-400	5 69	B	5.49	L
					M
				20	H
		6.62	BB	1 34	L
				4.37	M
				.91	H
		7.17	L	7.17	L
					M
					H
9 44	400-600	2.30	B	2.13	L
					M
				.17	H
		4.14	BB	.96	L
				2 42	M
				76	H
		3 00	L	3.00	L
					M
					H
14.67	600-1,000	3 42	B	3 30	L
					M
				.12	H
		5 21	BB	1.13	L
				3 41	M
				.67	H
		6 04	L	6 04	L
					M
					H
24 96	1,000+	12.66	B	12.55	L
					M
				.10	H
		5.86	BB	2 42	L
				2.73	M
				.51	H
		6 64	L	6.64	L
					M
					H
	All	29.61	B	28.57	L
					M
				1.04	H
		34.68	BB	8.02	L
				21.12	M
				5.54	H
		36.71	L	36 71	L
					M
					H

RAIL										
Percent of total ton-miles	Ton-miles (000,000 s)	Price ¢/ton-mile	Total revenue ($000)	Velocity (mph)	Avg. transp. cost ¢/ton-mile	Total transp. cost ($000)	Avg. safety cost ¢/ton-mile	Right of way acres/mi.	Poll & noise cost ¢/ton-mile	Total cost ($000)
0 08	1,568	6 2	97,216	15						
005	98	15 3	14,994	15						
10	1,882	6 2	116,684	15						
01	195	15.3	24,835	15						
.39	7,410	4 5	333,450	15						
62	11,864	5.5	652,520	15						
06	1,116	12 8	142,848	15						
.15	2,849	4 1	116,809	15						
54	10,348	2.89	299,057	18						
04	682	7.13	48,627	18						
.91	17,291	2 17	375,215	18						
1 46	27,683	2 55	705,917	18						
.14	2,006	5.97	155,519	16						
.35	6,648	1 92	127,642	18						
74	14,111	1.72	242,709	20						
08	1,511	4 20	63,462	20						
1.03	19,587	1.13	221,333	20						
2 04	38,800	1 52	589.760	20						
.31	5,825	3.55	206,788	20						
46	8,821	1.92	169,363	20						
84	15,993	1.31	209,508	20						
12	2,235	3 33	74,426	20						
.88	16,796	95	159,562	20						
1.86	35,458	1.19	421,950	20						
.45	8,579	2.75	161,673	20						
18	3,473	.90	31,257	20						
1 98	37,630	1.11	417,693	20						
08	1,587	2 78	44,119	20						
.86	16,291	80	130,328	20						
2 57	48,910	97	474,427	20						
.34	6,[illegible]20	2 29	149,308	20						
20	3,8[illegible]	.74	28,631	20						
12 20	232,064	.85	1,972,459	25						
.09	1,771	2.10	37,191	25						
2.26	42,941	.64	274,822	25						
2.36	44,882	.69	309,686	25						
.37	7,081	1.72	121,793	25						
.11	2,036	57	11,606	25						
16.49	313,586	1 07	3,358,370							
.42	8,079	2.95	238,331							
6.33	120,316	1.24	1,491,918							
10.91	207,597	1.53	3,176,234							
1.67	31,726	3.19	1,012,089							
1.46	27,696	1.50	415,440							

REGULATED TRUCK

Percent of total ton-miles	Ton-miles (000,000's)	Price ¢/ton-mile	Total revenue ($000)	Velocity (mph)	Avg. transp. cost ¢/ton-mile	Total transp cost ($000)	Avg. safety cost ¢/ton-mile	Right of way acres/mi	Poll. & noise cost ¢/ton-mile	Total cost ($000)
0.01	23[illegible]	18.0	42,660	20						
.05	89[illegible]	11 2	100,688	20						
[illegible]	4,1[illegible]8	20 6	853,608	20						
.06	1,228	32.2	395,416	20						
.15	2,866	3 3	94,578	20						
.02	371	8 4	31,164	25						
.02	316	18 0	53,880	25						
08	1,498	11 2	167,776	25						
.33	6,253	20.6	1,288,118	25						
.11	2,047	32.2	659,134	25						
.23	4,299	3 3	141,867	25						
.03	569	3.68	20,939	30						
08	1,502	8 11	121,812	30						
.33	6,291	4.90	308,259	30						
1.39	26,398	9 28	2,149,734	30						
.43	8,187	11.5	94,151	30						
.89	16,908	1.47	248,548	30						
.07	1,310	2.26	29,606	35						
.06	1,107	4 99	55,239	35						
22	4,194	2 96	124,142	35						
.95	18,062	5.65	1,020,508	35						
.27	5,117	8 79	449,784	35						
17	3,153	90	28,377	35						
009	173	1 70	2,941	35						
.02	395	3.82	15,089	35						
.0[illegible]	1,348	2.31	31,139	35						
.37	6,947	4 39	304,973	35						
.11	2,047	[illegible]	142,881	35						
05	860	.69	5,934	35						
003	49	1 42	696	40						
.01	277	3 18	8,809	40						
.04	748	1.85	13,838	40						
.31	6,252	3 62	226,322	40						
.06	1,433	5.77	82,684	40						
02	287	57	1,636	40						
.006	118	2 49	2,938	40						
.07	1,390	2.96	41,006	40						
.02	409	4.91	20,082	40						
.02	287	.46	1,320	40						
.13	2,472	3.88	95,914							
.21	3,953	7.67	303,195							
.79	14,978	4.98	745,904							
3.66	69,469	8.91	6,189,688							
1.08	20,468	12.73	2,605,576							
1.51	28,660	1.82	521,612							

PRIVATE TRUCK										
Percent of total ton-miles	Ton-miles (000,000's)	Price ¢/ton-mile	Total revenue ($000)	Velocity (mph)	Avg. transp. cost ¢/ton-mile	Total transp. cost ($000)	Avg. safety cost ¢/ton-mile	Right of way acres/mi	Poll. & noise cost ¢/ton-mile	Total cost ($000)
0 002	29	25	7,250	15						
.01	234	48	112,320	15						
01	107	86	92,020	15						
01	130	4 8	6,240	15						
03	580	17.2	99,760	20						
07	1 389	23 7	329,193	20						
.79	15,090	38 3	5,779,470	20						
.39	7,448	65 8	4,900,784	20						
40	7,663	4 0	306,520	20						
1.02	19 463	7 9	1,537,577	25						
05	942	17.2	162,024	25						
10	1,900	23 0	437,000	25						
1.13	21,523	38.3	8,243 309	25						
55	10,527	65 8	6,926,766	25						
.58	10,937	3 9	426,543	25						
1 80	34,242	3.39	1,162,499	30						
.19	3,696	7 82	289,027	30						
06	1,070	4 38	46,866	30						
1.72	32,731	8.72	2,854,143	30						
[illegible]	17,656	12 27	2,166,391	30						
74	14,148	.82	116,014	30						
1 71	32,439	2 11	684,463	35						
.05	870	4 74	41,238	35						
02	350	2 68	9,380	35						
40	7,599	5 27	400,467	35						
29	5,518	9 40	518,692	35						
09	1,769	.50	8,845	35						
29	5,561	1 62	90,088	35						
.03	507	3 68	18,658	35						
004	76	2 06	1,607	35						
.12	2,338	4 09	95,62[illegible]	35						
.14	2,575	7 46	192 095	35						
01	221	38	840	35						
05	927	[illegible]	12,329	40						
03	507	3 07	15,565	40						
001	20	1.70	340	40						
.09	1,754	3 45	60,513	40						
.15	2,943	6.14	180,700	40						
01	221	30	66[illegible]	40						
007	146	2,40	3,504	40						
03	585	2,72	15,912	40						
.04	735	5 28	38,808	40						
4.87	92,68[illegible]	3,76	3,484,843							
.38	7,248	8 70	630,576							
.25	4,836	5.19	250,988							
4.30	81,854	10.32	8,447,333							
2 50	47,509	15 30	7,268,877							
1,84	35,089	1.[illegible]	376,452							

WATER										
Percent of total ton-miles	Ton-miles (000,000's)	Price ¢/ton-mile	Total revenue ($000)	Velocity (mph)	Avg. transp cost ¢/ton-mile	Total transp. cost ($000)	Avg. safety cost ¢/ton-mile	Right of way acres/mi	Poll. & noise cost ¢/ton-mile	Total cost ($000)
0 07	1,347	1.09	14,682	4						
0003	5	.92	46	4						
02	370	1.13	4,181	4						
002	40	1 11	444	4						
.14	2,694	1.10	29,634	5						
0006	10	92	92	5						
.03	494	1.13	5,582	5						
03	501	.81	4,058	5						
002	40	1 10	440	5						
1.04	19,733	76	149,971	5						
1 27	24,246	49	118,805	6						
004	92	42	386	6						
.14	2,715	.50	13,575	6						
.50	9,528	.30	28,584	6						
01	159	.50	795	6						
2 82	53,561	.34	182,107	6						
2 97	56,575	40	276,300	6						
01	214	.36	770	6						
07	1,357	.41	5,564	6						
98	18,578	30	55,734	6						
03	557	.41	2,284	6						
1.33	25,371	.28	71,039	6						
.99	18,858	.33	62,231	6						
.003	71	.28	199	6						
006	123	.33	406	6						
07	1,347	.24	3,233	6						
04	757	.34	2,574	6						
.74	14,095	.23	32,419	6						
1.27	24,246	.29	70,313	10						
005	92	.23	212	10						
.23	4,319	30	12,957	10						
42	7,908	.32	25,306	10						
.07	1,354	.30	4,062	10						
3 56	67,656	.20	135,312	10						
.35	6,736	.27	18,187	12						
001	25	.23	58	12						
.16	2,961	27	7,995	12						
.27	5,164	.20	10,328	12						
.06	1,075	.34	3,656	12						
5.33	101,483	.27	274,004	12						
7 08	134,702	.40	538,808							
03	509	.31	1,731							
.65	12,339	.41	50,590							
2.26	43,028	.29	124,775							
.21	3,982	.34	13,539							
14.82	281,899	.27	761,127							

PIPELINE										
Percent of total ton miles	Ton-miles (000,000's)	Price ¢/ton-mile	Total revenue ($000)	Velocity (mph)	Av. transp cost ¢/ton-mile	Total transp cost ($000)	Avg. safety cost ¢/ton-mile	Right of way acres/mi.	Poll. & noise cost ¢/ton-mile	Total cost ($000)
0 55	10,493	76	79,747	2						
1 10	20,985	.64	134,304	2						
3.86	73,449	.30	220,347	3						
5.12	97,461	.23	224,160	3						
2 02	38,372	21	80,581	3						
2.25	42,748	.19	81,221	3						
1.18	22,432	.17	38,236	3						
16 09	306,000	.28	856,800							

AIR										
Percent of total ton-miles	Ton-miles (000,000's)	Price ¢/ton-mile	Total revenue ($000)	Velocity (mph)	Avg. transp cost ¢/ton-mile	Total transp. cost ($000)	Avg. safety cost ¢/ton-mile	Right of way acres/mi.	Poll. & noise cost ¢/ton-mile	Total cost ($000)
0.002	47	71.6	33,652	150						
.01	266	29.8	79,268	200						
.02	313	21	65,730	250						
.03	486	19	42,340	300						
.02	451	17	76,670	350						
.08	1,863	20.46	319,790							

NEW MODES											
New mode identification	Percent of total ton-miles	Total ton-miles (000,000's)	Price ¢/ton-mile	Total revenue ($000)	Velocity (mph)	Avg. transp. cost ¢/ton-mile	Total transp cost ($000)	Avg. safety cost ¢/ton-mile	Right of way acres/mi.	Poll. & noise cost ¢/ton-mile	Total cost ($000)
Slurry pipeline			1.0		2-3						
Capsule pipeline					2						
Capsule pipeline					2						
Capsule pipe					2						
Capsule pipe					2						
Auto, lg. dia pipe			3		3						
Slurry pipeline			1 0		2 3						
Capsule pipe					2						
Capsule pipe					2						
Capsule pipe					2						
Auto, lg. dia. pipe			.3		3						
Slurry pipeline			1 0		2 3						
Capsule pipe					2						
Capsule pipe					2						
Capsule pipe					2						
Auto, lg. dia. pipe			.3		3						
Slurry pipeline			1.0		2 3						
Trk-tlr trains					60						
Trk-tlr trains					60						
Auto, lg. dia. pipe			3		2-3						
Coaxial train			1.25		100						
Trk tlr trains			–		60						
Coaxial train			1.25		100						
Trk tlr trains			–		60						
Auto, lg dia. pipe			.3		60						
Coaxial train			1 25		100						
Roll on-off ships			0 7		20-25						
Truck-trailer trains			–		60						
Coaxial train			1.25		100						
B 747, L-500			10 00		600						
Aereon 340, Guppy			7-18, 20		300						
Roll on-off ships			0.7		20-25						
Trk tlr trains			–		60						
Coaxial train			1.25		100+						
Roll on-off ships			0 7		20-25						
B 747, L-500			10.00		600						
Aereon 340, Guppy			7-20, 18		300						
Coaxial train			1.25		100+						
Roll on-off ships			0 7		20-25						
B 747, L-500			10 00		600						
Aereon 340, Guppy			7-20, 18		300						

APPENDIX 3

List of Delphi Participants

Urban Systems

Mr. E. S. Chaney, Battelle Memorial Institute
Mr. W. Hamilton, General Research Corp.
Mr. G. Kuthey, American Academy of Transportation
Mr. S. Myers, Institute of Public Admin.
Mr. F. Pardee, RAND Corporation
Dr. F. Hassler, MITRE Corporation
Mr. C. Henderson, Stanford Research Institute
Mr. R. Makofski, Johns Hopkins University
Mr. R. H. Shackson, Ford Motor Company

Interurban Systems

Dr. J. V. Foa, Rensselaer-Polytechnic Institute
Mr. J. Kimball, AiResearch Manufacturing Co.
Mr. G. Grubelich, Grumman Aerospace Corp.
Mr. H. Ross, Transportation Technology Inc.
Mr. W. P. Bollinger, Westinghouse Electric Corp.
Mr. N. N. Davis, General Electric Co.
Mr. W. Mason, MITRE Corporation
Professor W. Seifert, MIT
Mr. J. Vadenboncoeur, TRW
Mr. F. Altman, University of Pennsylvania

Air Mode Systems

Professor R. W. Simpson, MIT
Mr. J. L. Burton, McDonnell Douglas
Mr. R. B. Meyersburg, FAA
Mr. R. Wagner, Hughes Tool Company
Mr. F. W. Kolk, American Airlines
Mr. J. E. Gathings, LTV Aerospace Corp.
Mr. T. Courtney, North American Rockwell Inc.
Mr. R. H. Shatz, Sikorsky Aircraft Corp.
Mr. J. Hesse, United Aircraft Research Lab.
Mr. N. J. Asher, IDA

i - Tabularized Results - Cycle 2

ARRAY 1
URBAN SYSTEMS

	1975						1980						1990						2000					
	R/D COST			PROBABILITY			R/D COST			PROBABILITY			R/D COST			PROBABILITY			R/D COST			PROBABILITY		
SYSTEM	E($)	S.D.	N	E(P)	S.D.	N	E($)	S.D.	N	E(P)	S.D.	N	E($)	S.D.	N	E(P)	S.D.	N	E($)	S.D.	N	E(P)	S.D.	N
MAC-1	14.1	8.4	8	.60	.27	8	20.9	14.5	8	.78	.15	8	22.9	16.9	8	.92	.04	8	24.5	20.4	8	.97	.03	8
MAC-2	22.5	14.1	8	.56	.24	8	30.4	19.9	8	.83	.08	8	33.7	22.0	8	.92	.07	8	37.7	25.9	8	.96	.04	8
D-A-B	7.7	5.1	8	.89	.10	8	9.3	5.9	8	.98	.03	8	10.2	7.1	8	.99	.02	8	11.1	8.5	8	.99	.01	8
PAS	9.8	4.4	8	.76	.15	8	11.2	5.9	8	.91	.07	8	12.7	7.2	8	.94	.05	8	14.0	8.5	8	.95	.05	[illegible]
NET-1,2	55.1	68.7	8	.66	.16	8	70.7	98.1	8	.84	.10	8	87.9	129.9	8	.91	.10	8	102.2	160.9	8	.95	.08	8
NET-3	38.0	20.8	8	.39	.24	8	64.8	53.2	8	.65	.11	8	89.6	79.4	8	.83	.12	8	108.9	101.3	8	.90	.10	8
FTL-1	90.9	86.1	8	.36	.27	8	[illegible]	47.7	8	.64	.19	8	114.5	78.0	8	.82	.10	8	108.2	54.4	8	.92	.06	8
FTL-2	187.5	127.0	8	.14	.14	8	172.9	106.2	8	.44	.18	8	198.1	105.4	8	.67	.16	8	212.2	58.5	8	.81	.18	8

ARRAY 1
INTERURBAN SYSTEMS

	1975						1980						1990						2000					
	R/D COST			PROBABILITY			R/D COST			PROBABILITY			R/D COST			PROBABILITY			R/D COST			PROBABILITY		
SYSTEM	E($)	S.D.	N	E(P)	S.D.	N	E($)	S.D.	N	E(P)	S.D.	N	E($)	S.D.	N	E(P)	S.D.	N	E($)	S.D.	N	E(P)	S.D.	N
HSR-A	30.2	46.0	8	.93	.03	8	23.7	28.0	8	.94	.09	8	19.3	16.2	8	.92	.16	8	19.6	16.4	8	.89	.24	8
HSR-C	54.3	67.7	8	.63	.24	8	77.9	87.5	8	.80	.23	8	86.6	89.1	8	.85	.25	8	77.4	91.4	8	.87	.26	8
TACV	124.[illegible]	94.0	8	.64	.14	8	150.4	84.9	8	.86	.09	8	184.0	120.4	8	.93	.05	8	197.5	128.2	8	.94	.05	8
TVS	306.3	416.7	8	.26	.11	8	415.5	384.9	8	.64	.15	[illegible]	388.7	251.5	8	.86	.11	8	416.4	242.2	8	.91	.09	8
AUTO PALET	80.2	77.2	7	.71	.13	7	88.9	50.7	7	.85	.14	7	133.5	114.8	7	.94	.05	7	138.0	111.4	7	.98	.02	7

ARRAY 1
AIR SYSTEMS

	1975						1980						1990						2000					
	R/D COST			PROBABILITY			R/D COST			PROBABILITY			R/D COST			PROBABILITY			R/D COST			PROBABILITY		
SYSTEM	E($)	S.D.	N	E(P)	S.D.	N	E($)	S.D.	N	E(P)	S.D.	N	E($)	S.D.	N	E(P)	S.D.	N	E($)	S.D.	N	E(P)	S.D.	N
HELICOPTER	92.6	53.2	10	.81	.19	10	230.4	111.1	10	.81	.14	10	0.0	0.0	0	0.00	0.00	0	0.0	0.0	0	0.00	0.00	0
LITE AIRCT	5.3	4.8	9	.93	.09	9	26.0	45.7	9	.91	.15	9	26.2	25.7	9	.87	.17	9	0.0	0.0	0	0.00	0.00	0
LITE VTOL	0.0	0.0	0	0.00	0.00	0	0.0	0.0	0	0.00	0.00	0	160.2	241.4	10	.81	.15	10	93.1	45.6	10	.79	.17	10
3RD AIRCT	24.9	19.9	9	.93	.07	9	31.7	23.8	9	.90	.12	9	43.3	30.1	9	.92	.07	9	61.9	39.1	9	.92	.12	9
STOL	167.2	109.7	10	.88	.10	10	308.5	127.6	10	.71	.22	10	0.0	0.0	0	0.00	0.00	0	0.0	0.0	0	0.00	0.00	0
VTOL	0.0	0.0	0	0.00	0.00	0	388.1	157.9	10	.76	.17	10	517.3	232.2	10	.76	.15	10	793.4	298.0	10	.74	.22	10
SUB JET	251.5	196.4	9	.95	.05	9	378.8	304.3	9	.80	.27	9	766.0	690.3	9	.82	.16	9	0.0	0.0	0	0.00	0.00	0
SUPER JET	0.0	0.0	0	0.00	0.00	0	792.2	471.9	9	.89	.07	9	1364.7	470.9	9	.87	.09	9	2071.	963.6	9	.83	.13	9

Response Graphs

for

Transportation System

of

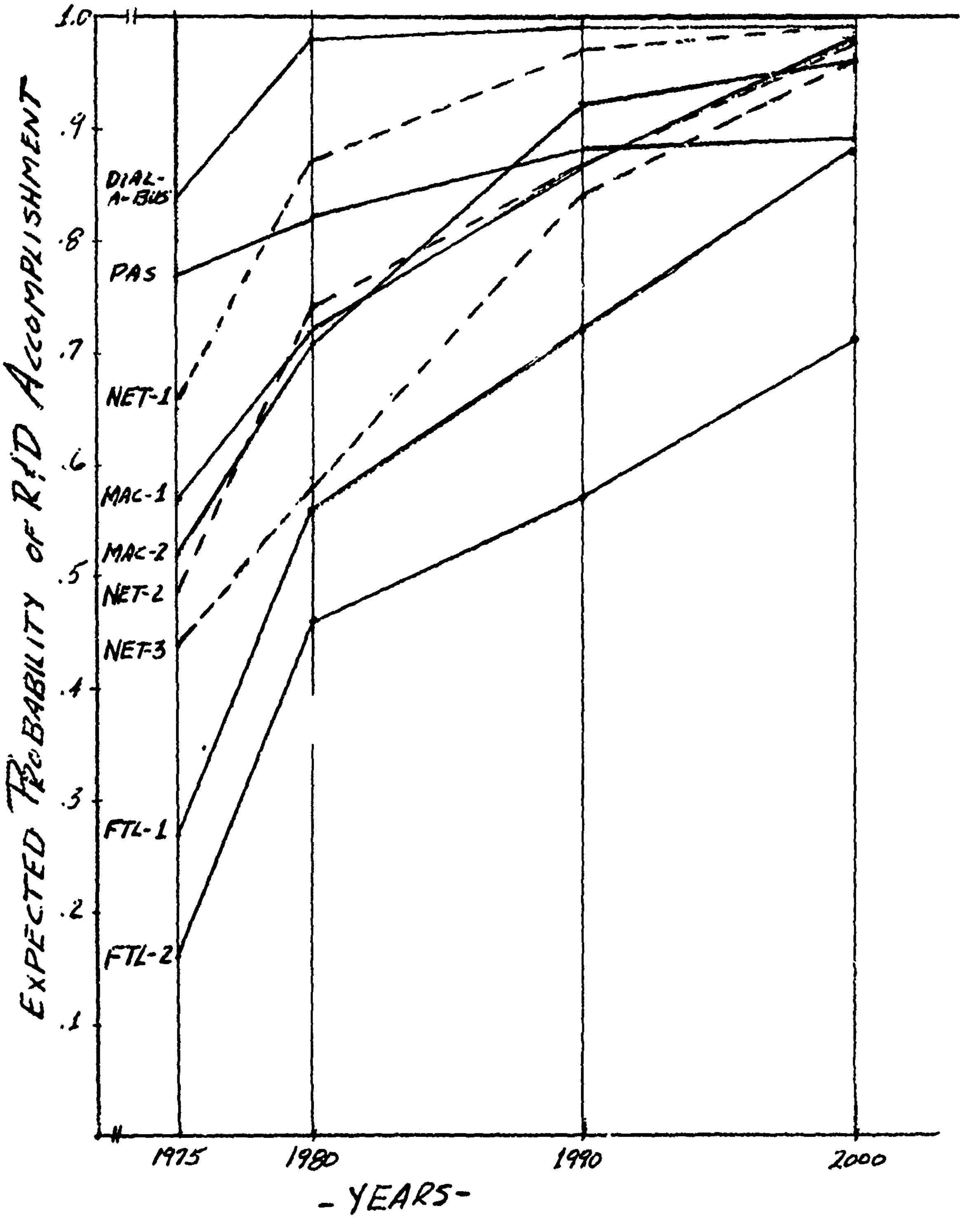
Delphi Exercise

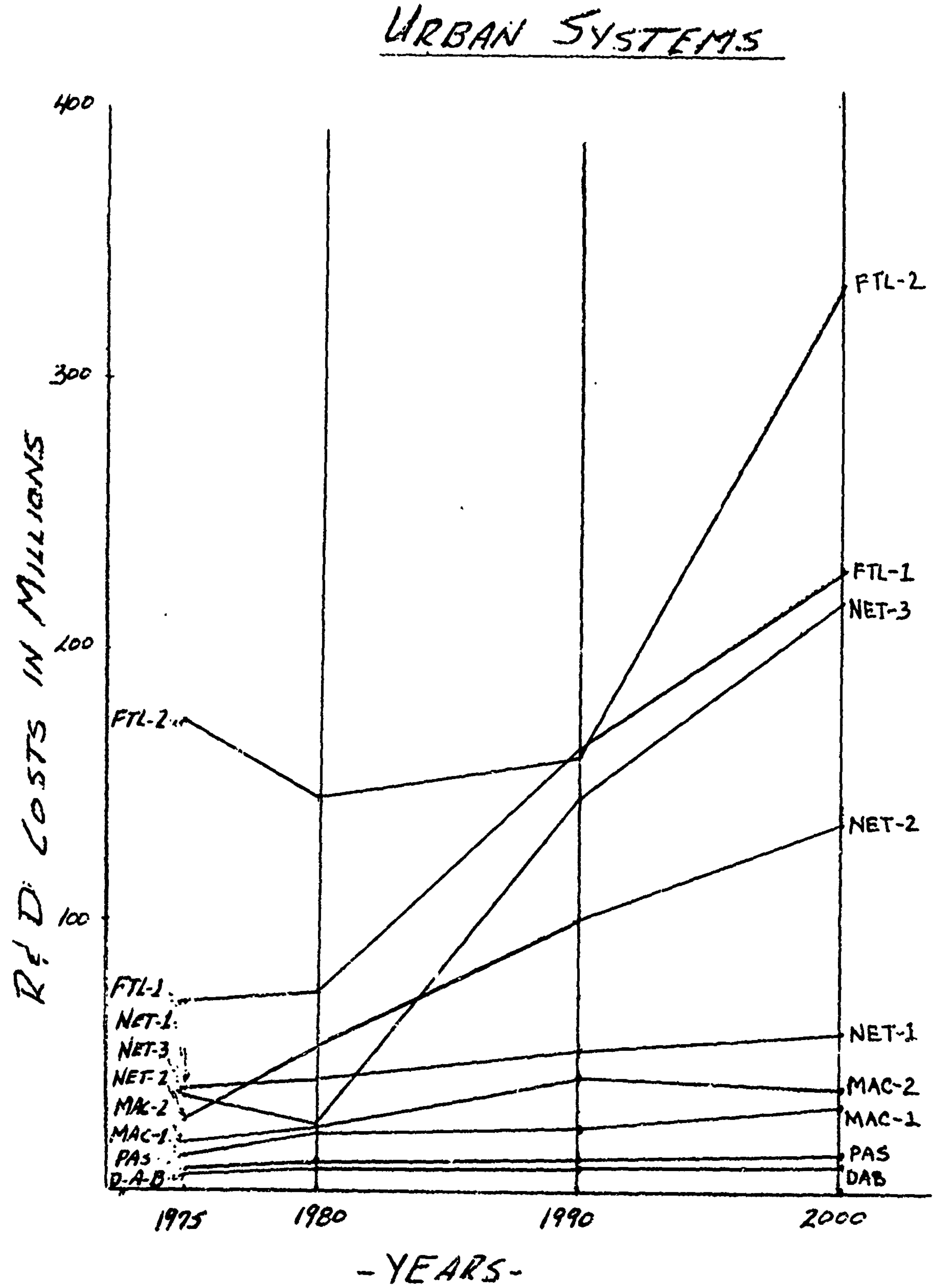
1st Cycle

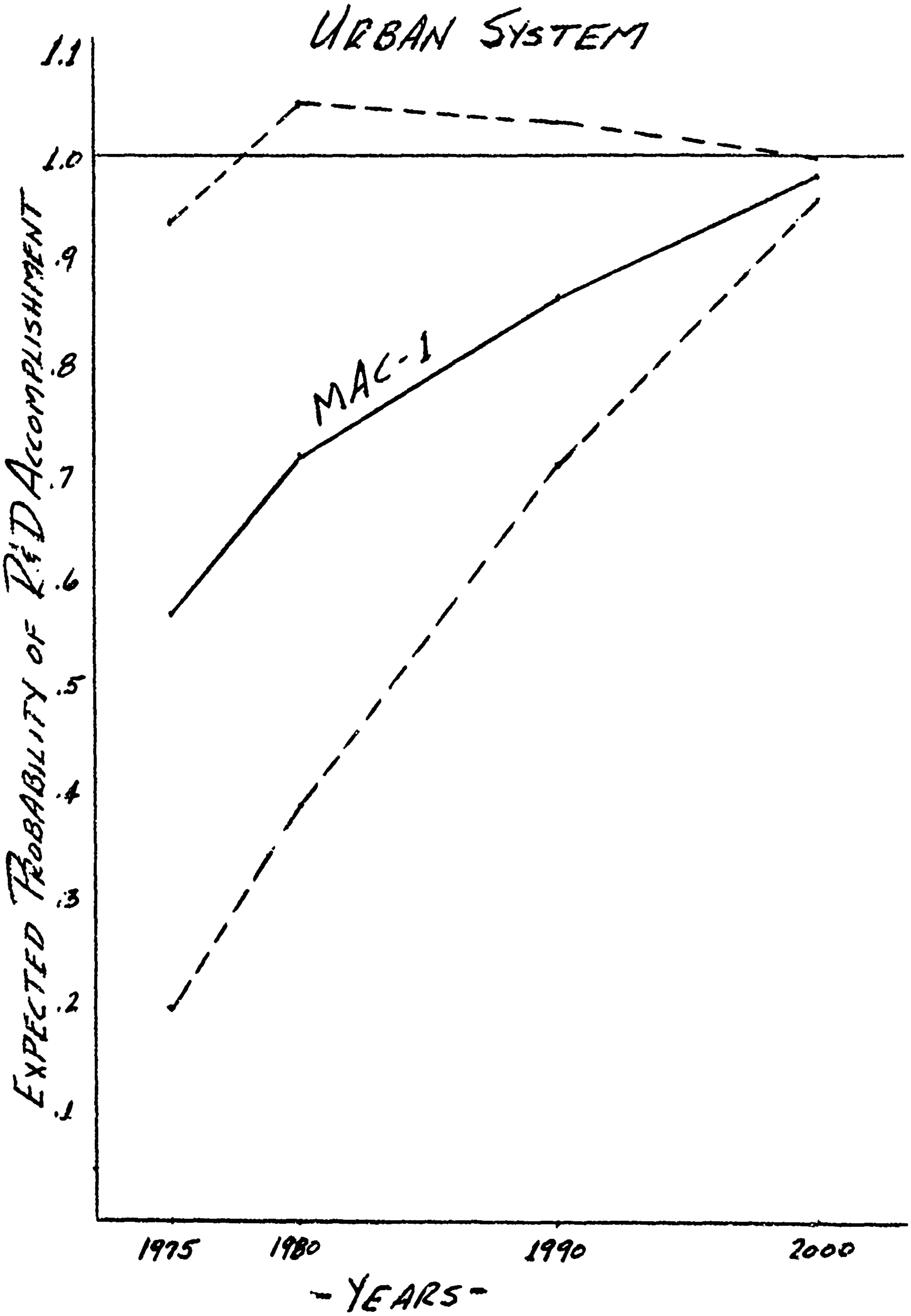
(February 1970)

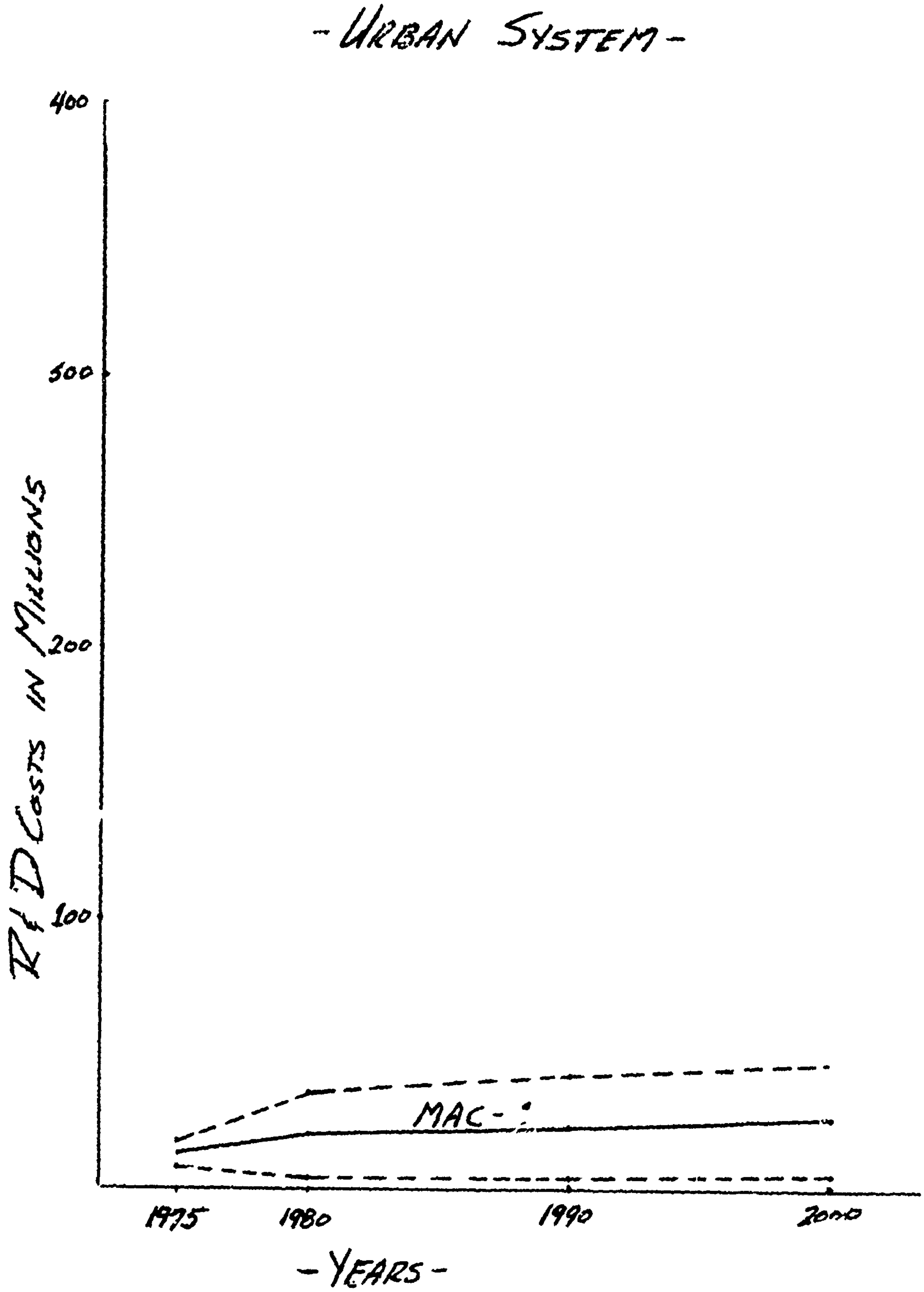
Office of Systems Requirements,
Plans and Information

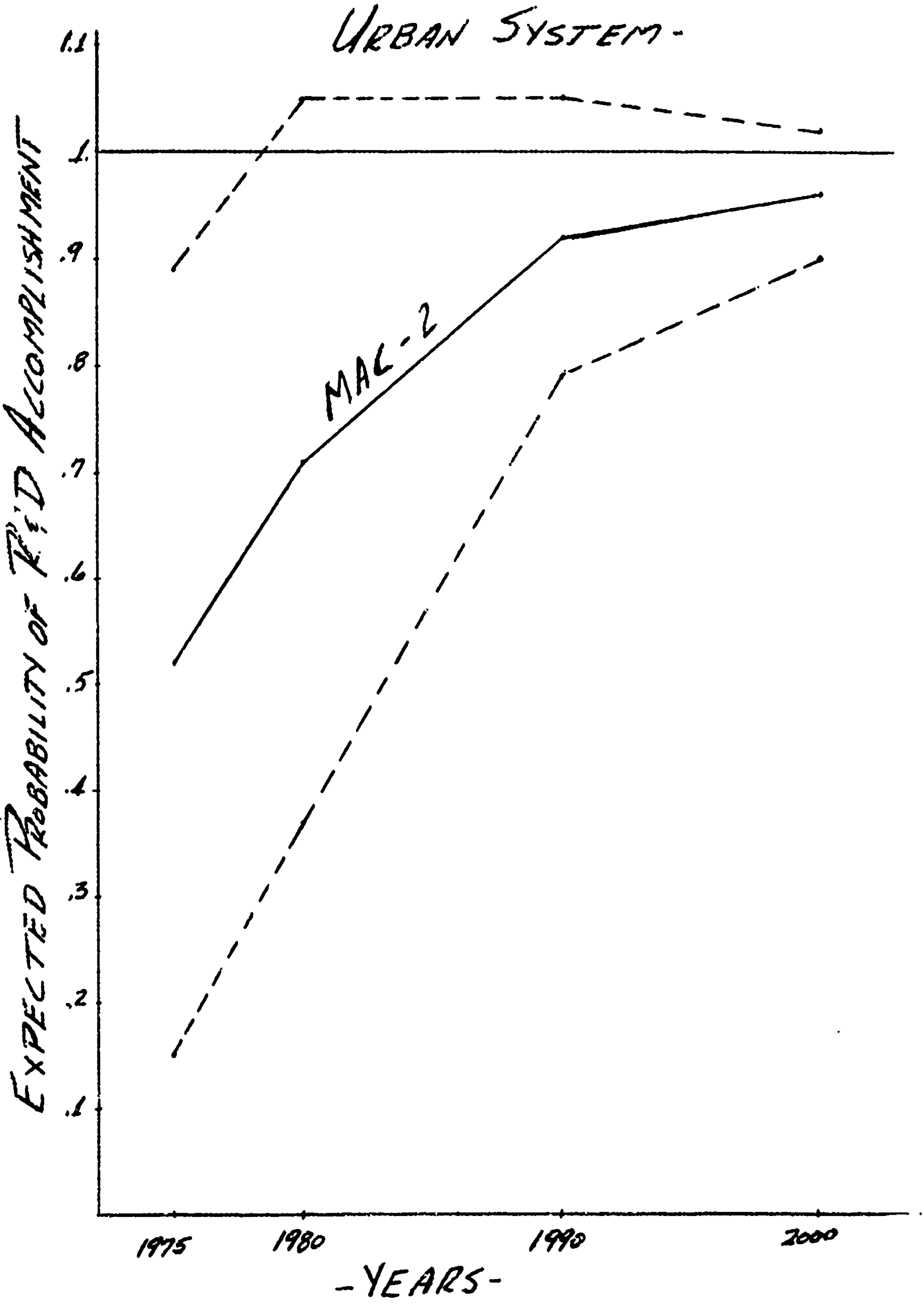
- URBAN SYSTEMS -



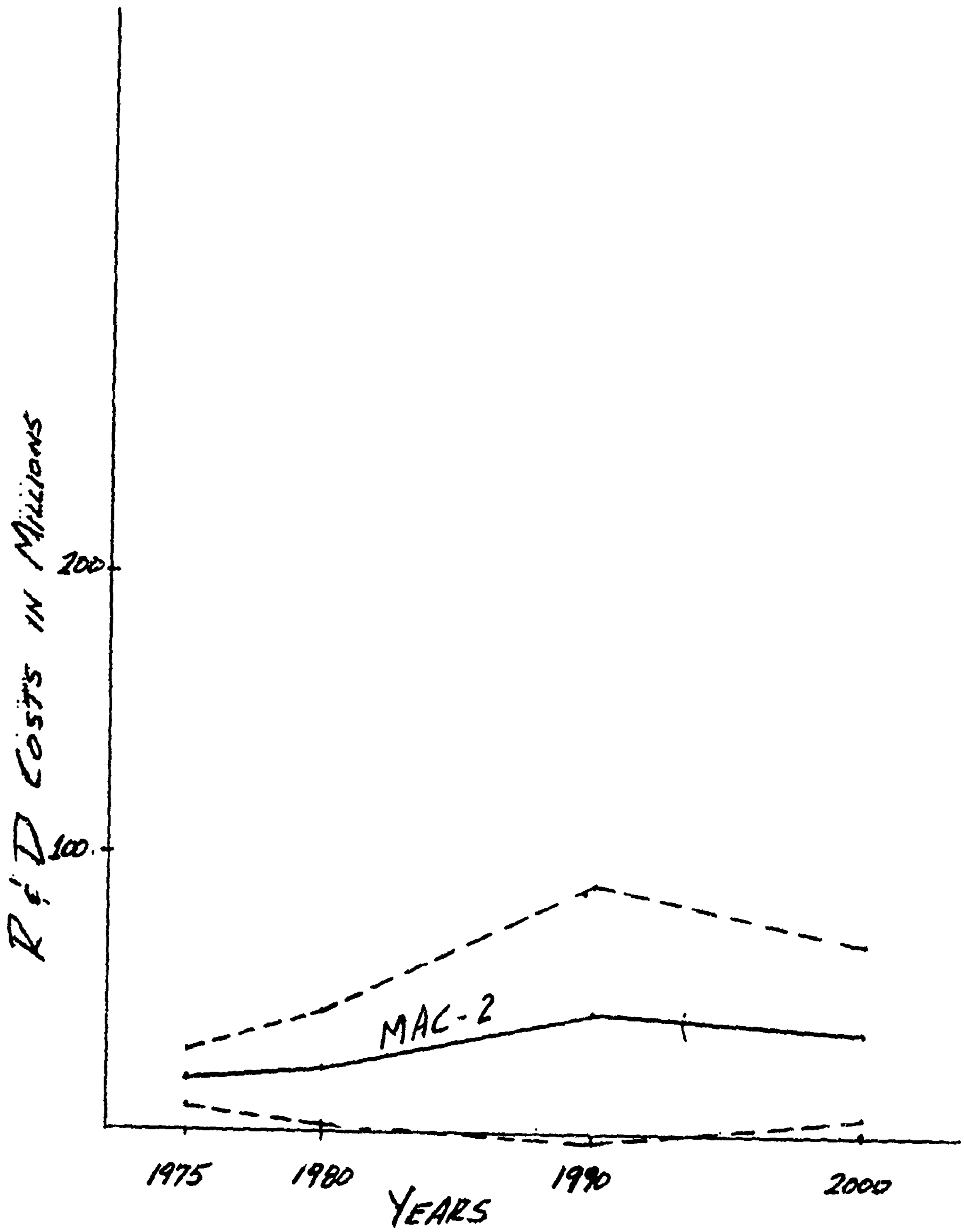

URBAN SYSTEMS
400
300
200
100
R&D COSTS IN MILLIONS
FTL-2
FTL-1
NET-1
NET-3
NET-2
MAC-2
MAC-1
PAS
D-A-B
FTL-2
FTL-1
NET-3
NET-2
NET-1
MAC-2
MAC-1
PAS
DAB
1975
1980
1990
2000
-YEARS-


URBAN SYSTEM
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
MAC-1
1975
1980
1990
2000
- YEARS -

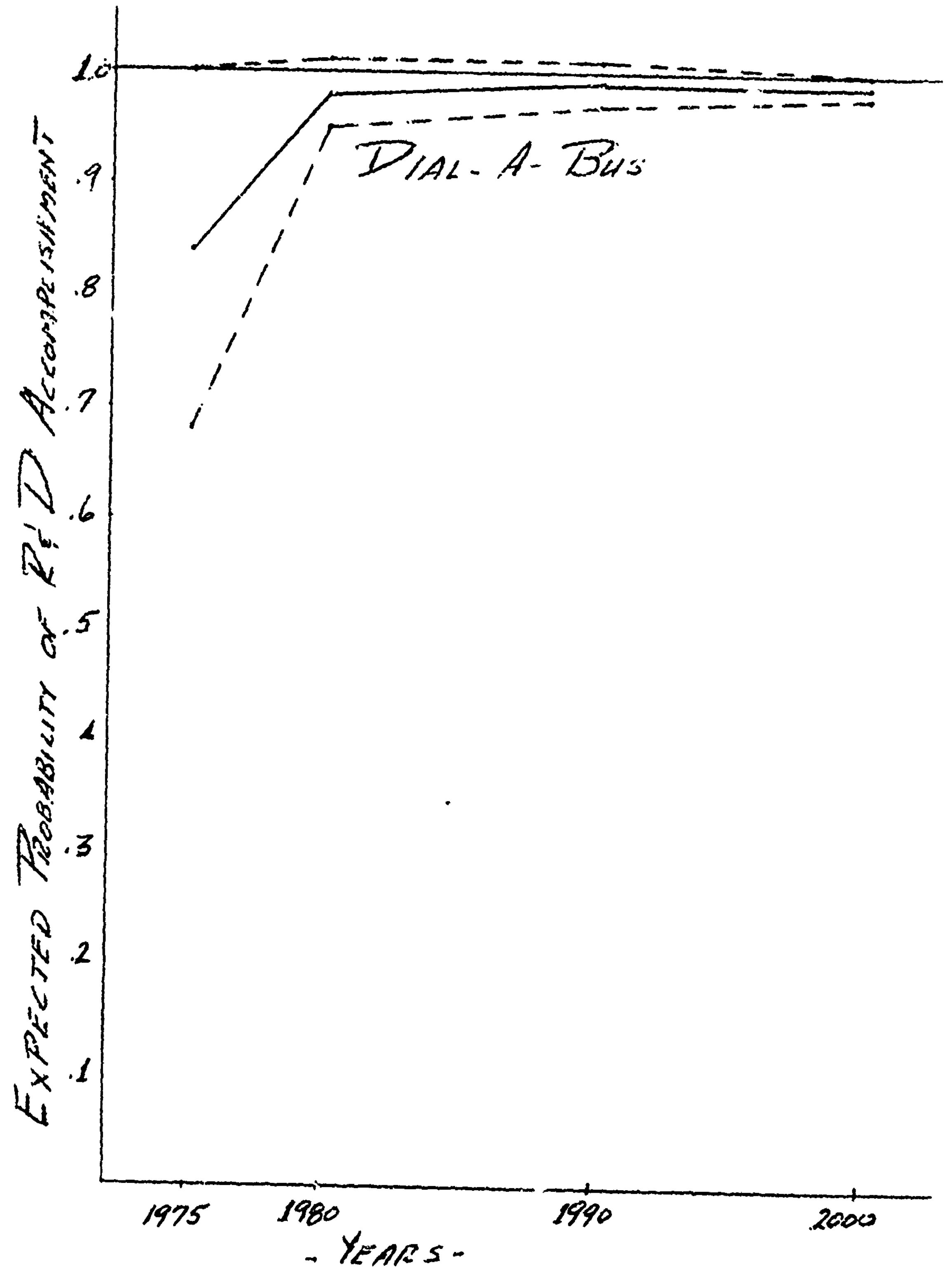

-URBAN SYSTEM-
400
500
200
100
R&D COSTS IN MILLIONS
MAC-
1975
1980
1990
2000
-YEARS-


URBAN SYSTEM-
1.1
1.
.9
.8
.7
.6
.5
.4
.3
.2
.1
MAC-2
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1975
1980
1990
2000
-YEARS-

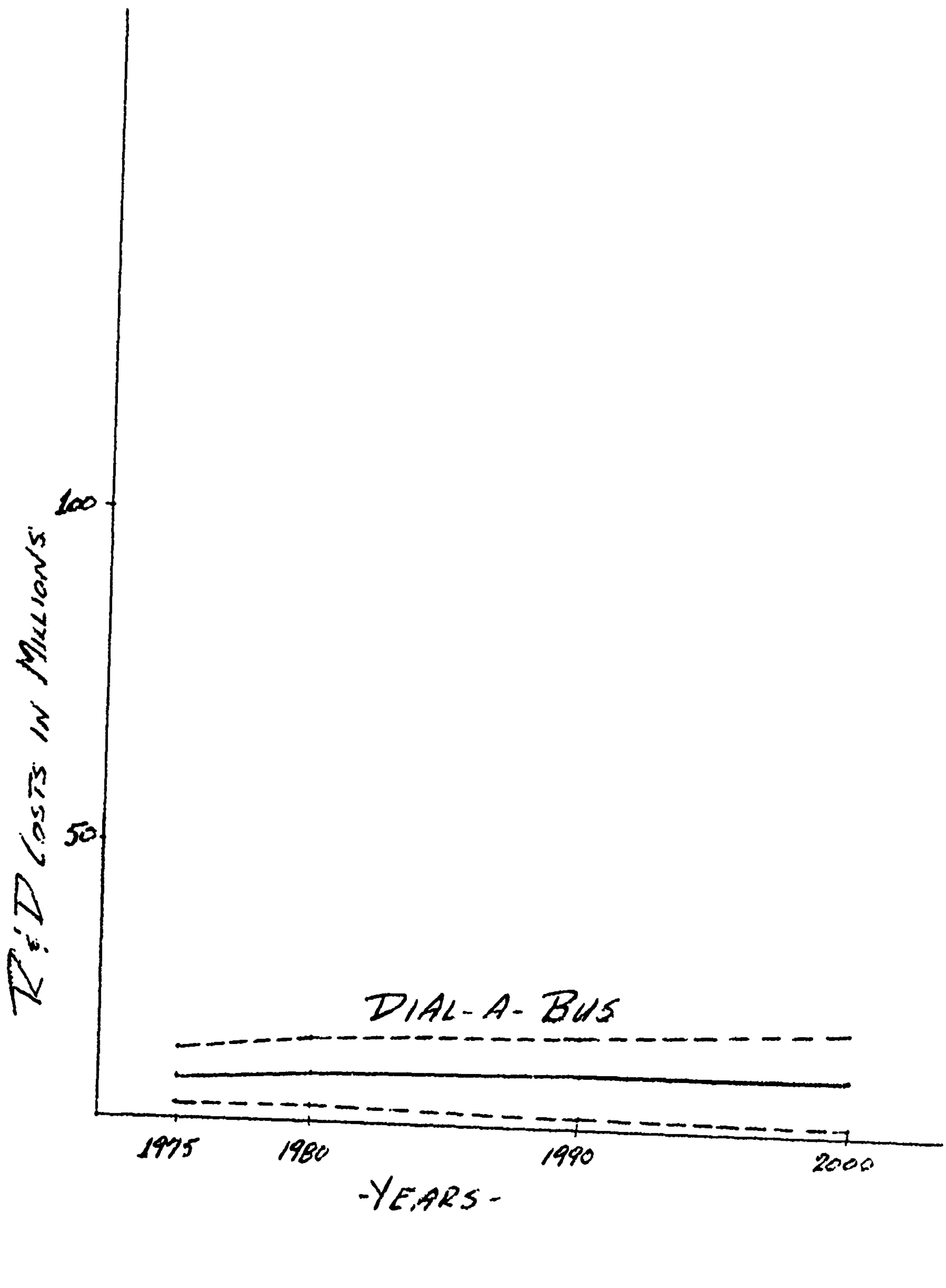
URBAN SYSTEM

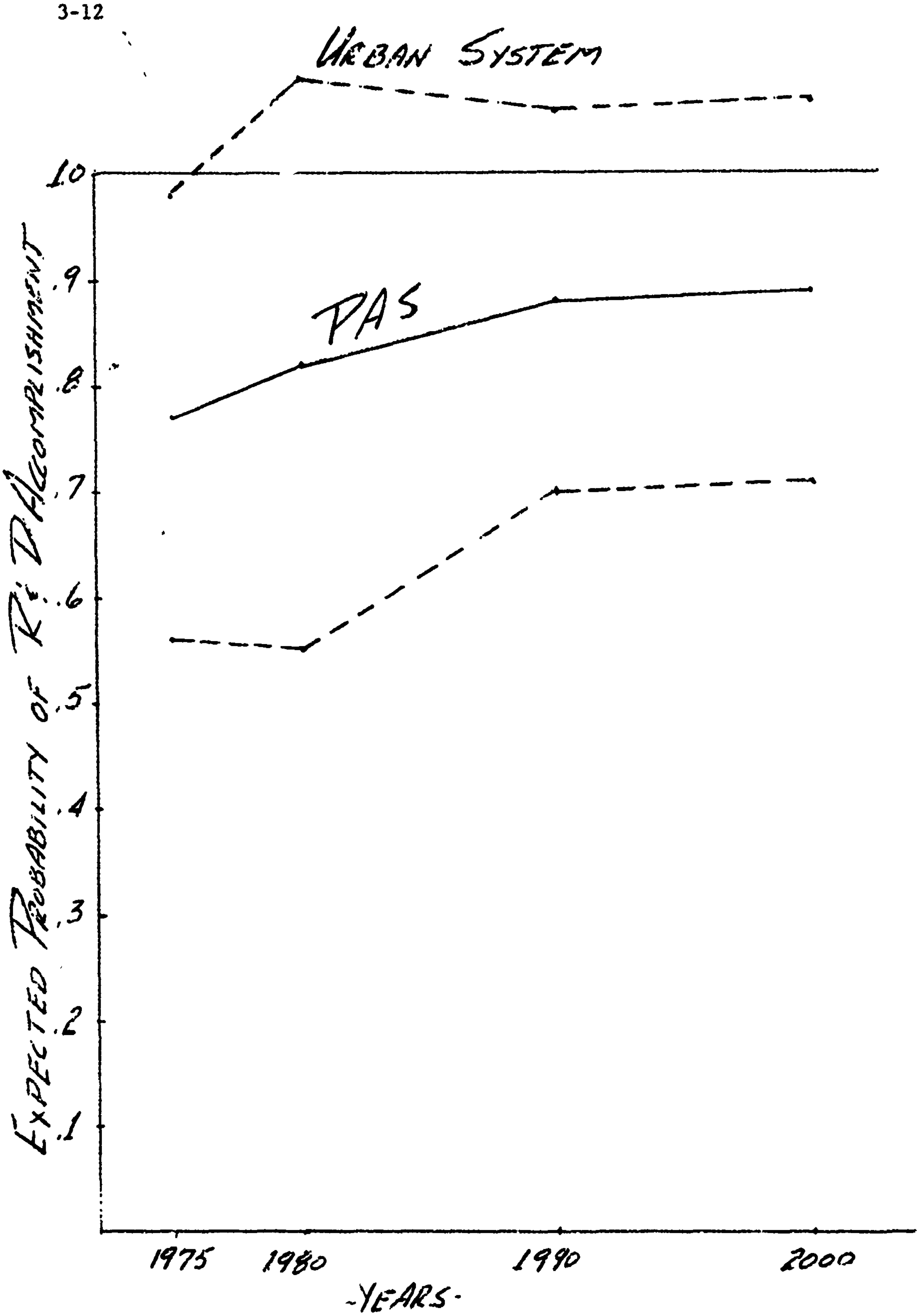


URBAN SYSTEM

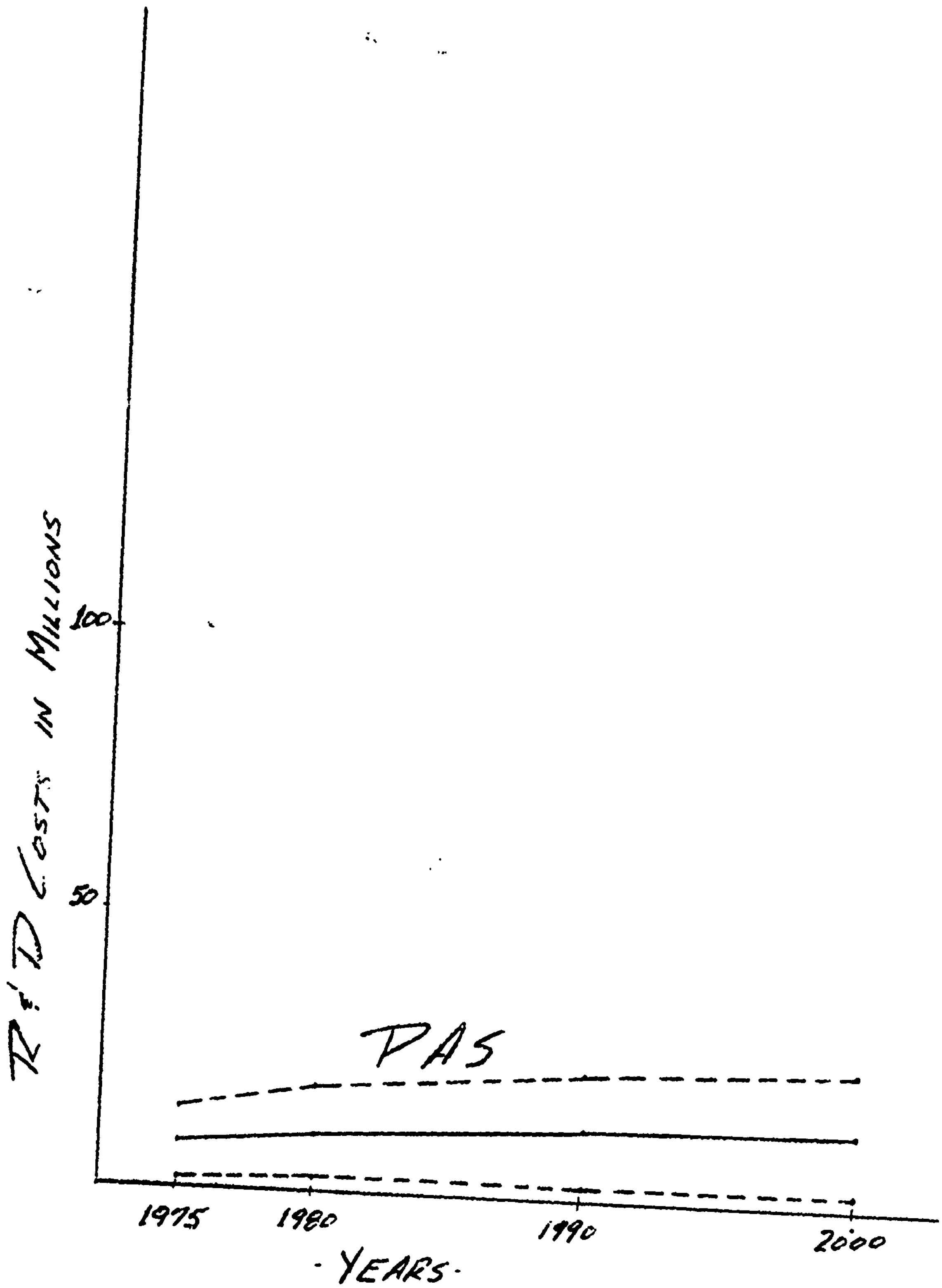


URBAN SYSTEM

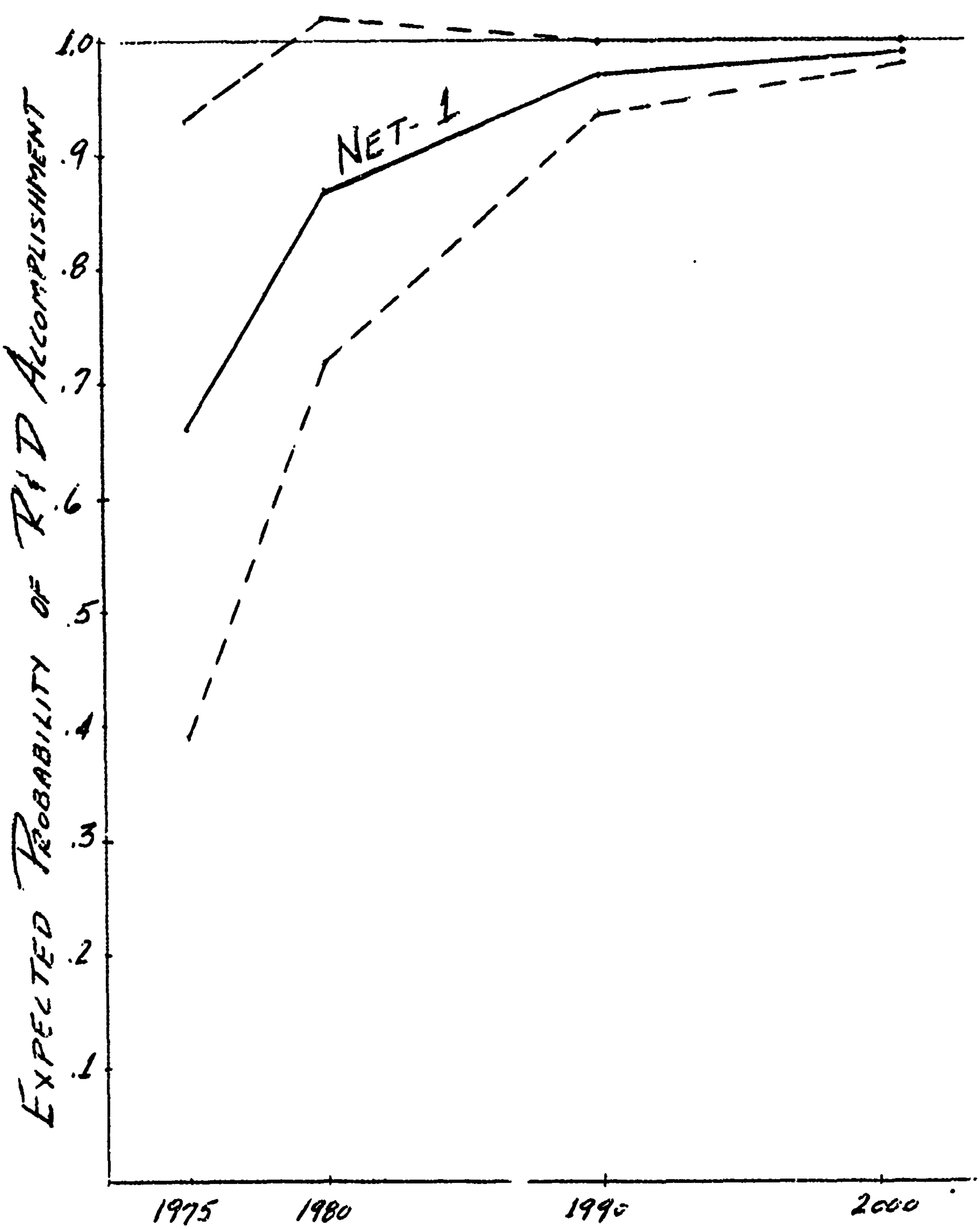



URBAN SYSTEM
PAS
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1975
1980
1990
2000
-YEARS-

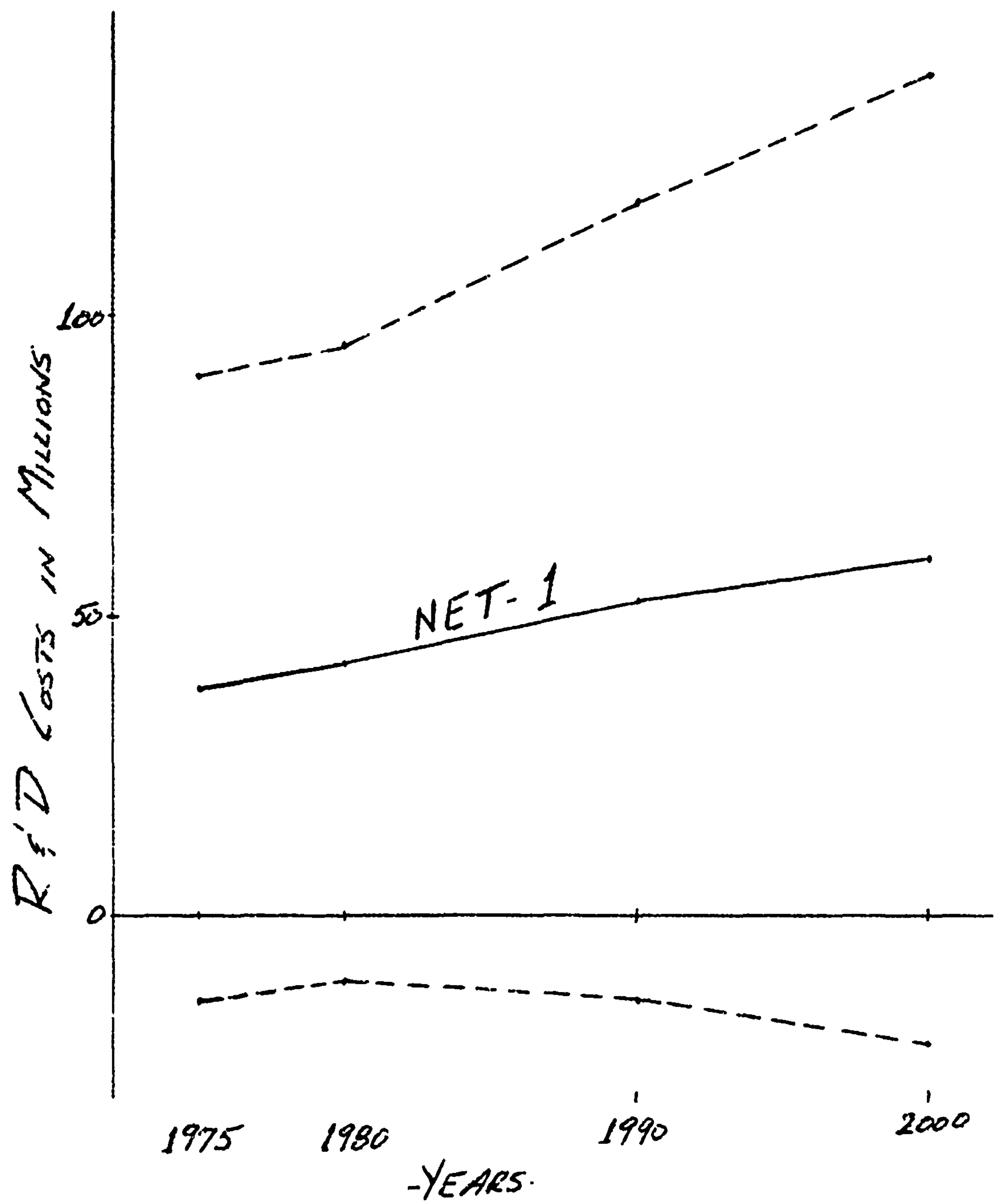
URBAN SYSTEMS

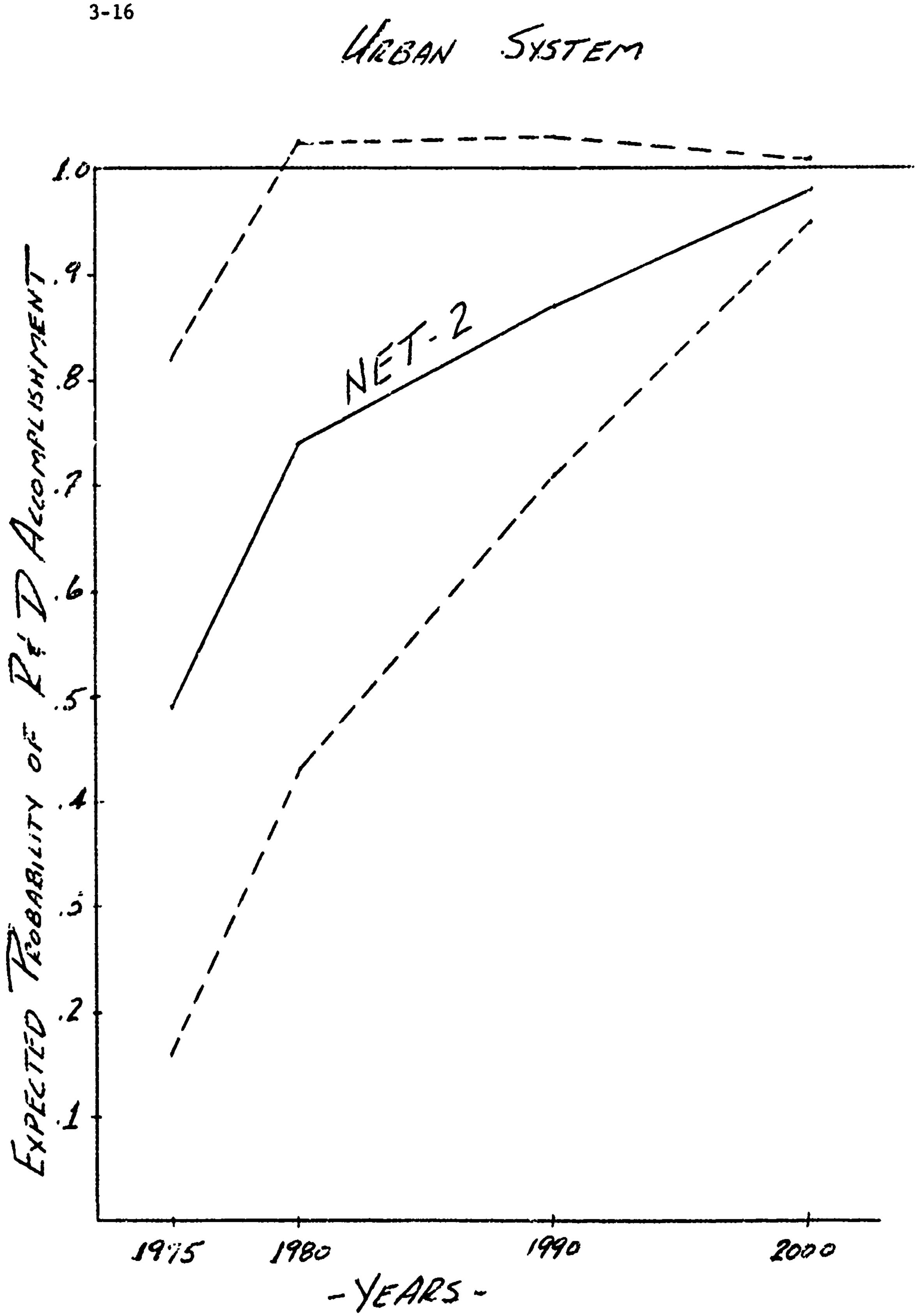


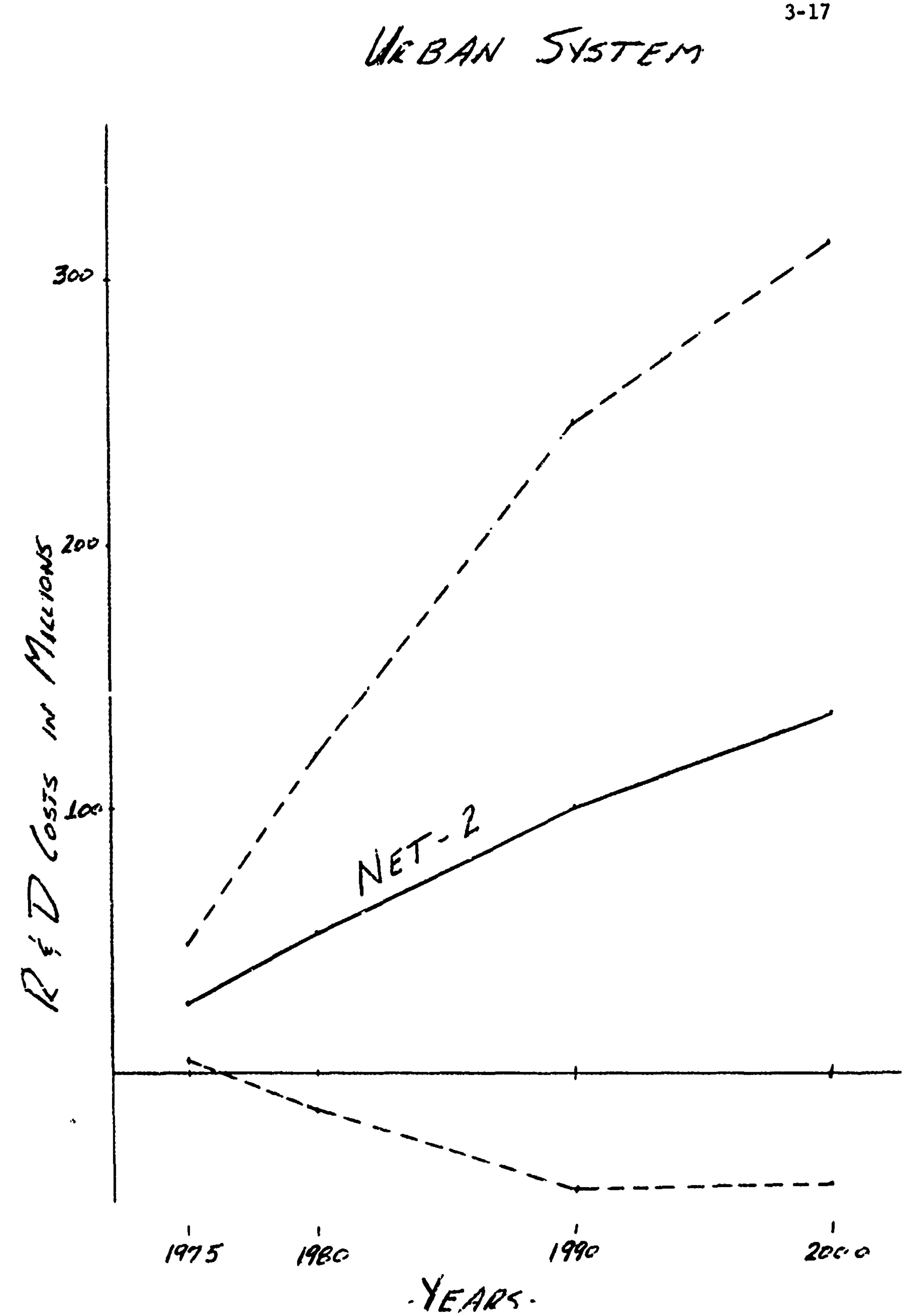
URBAN SYSTEM



URBAN SYSTEM

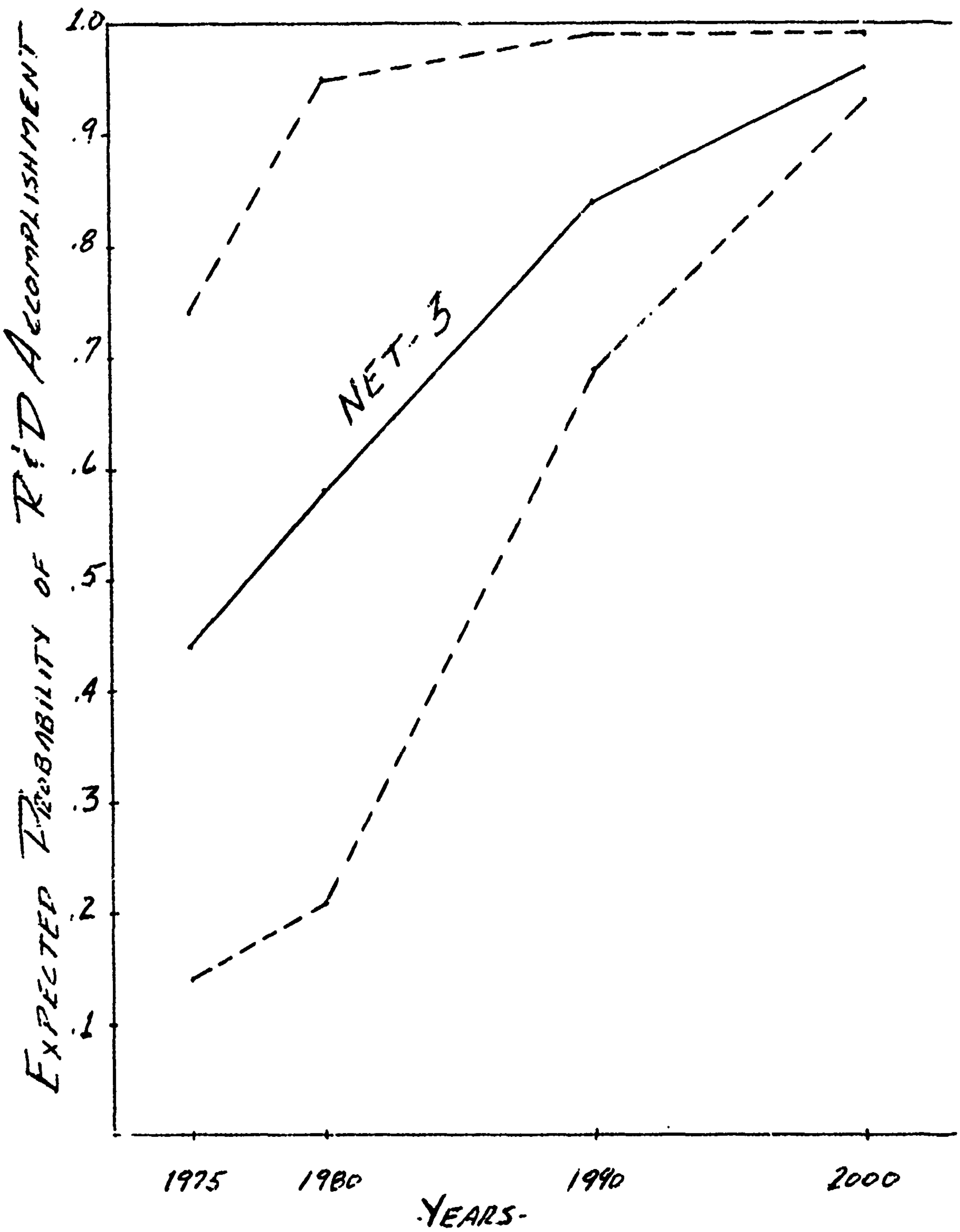



URBAN SYSTEM
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
NET-2
1975
1980
1990
2000
-YEARS-

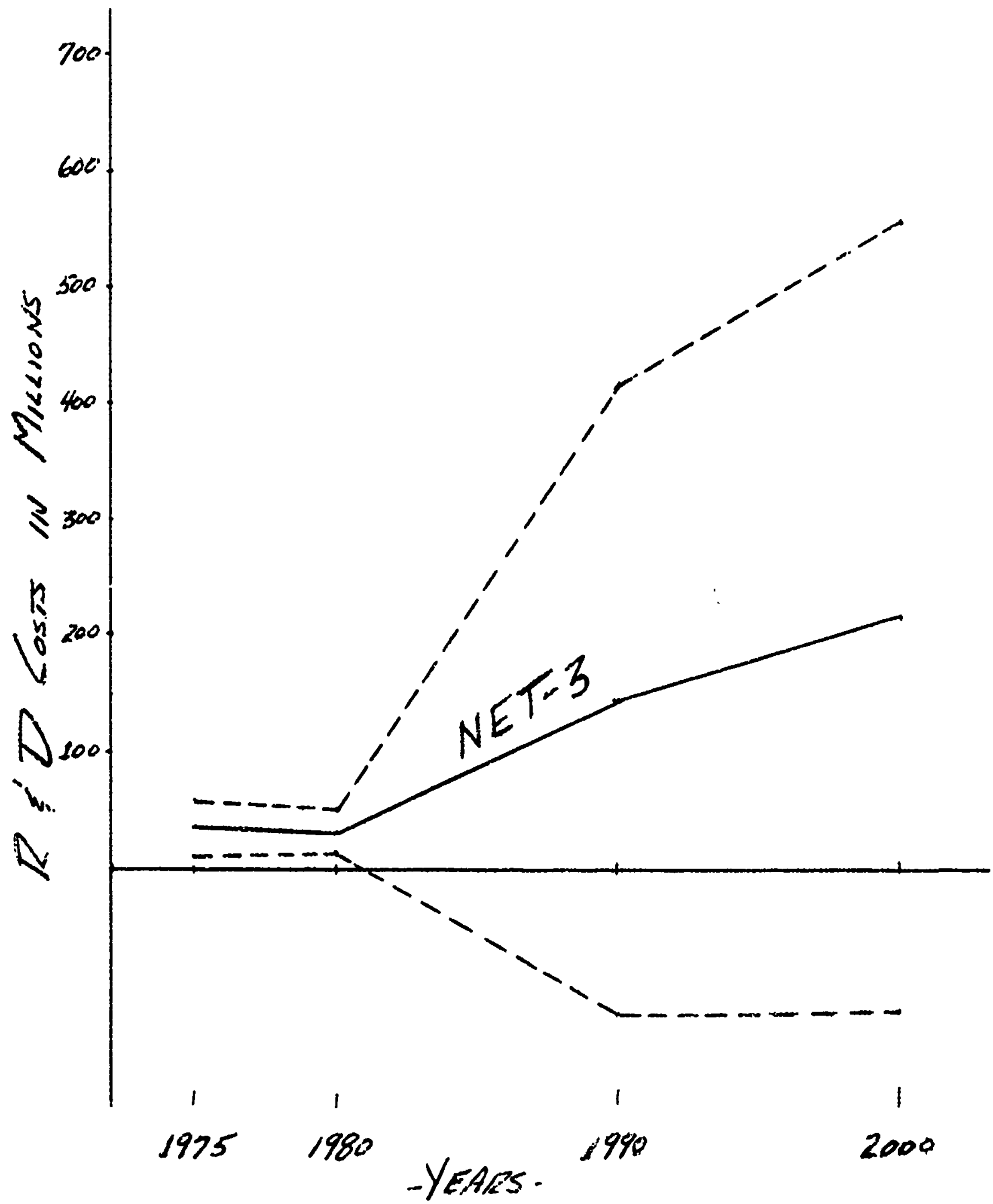

URBAN SYSTEM
300
200
100
R & D COSTS IN MILLIONS
NET-2
1975
1980
1990
2000
YEARS

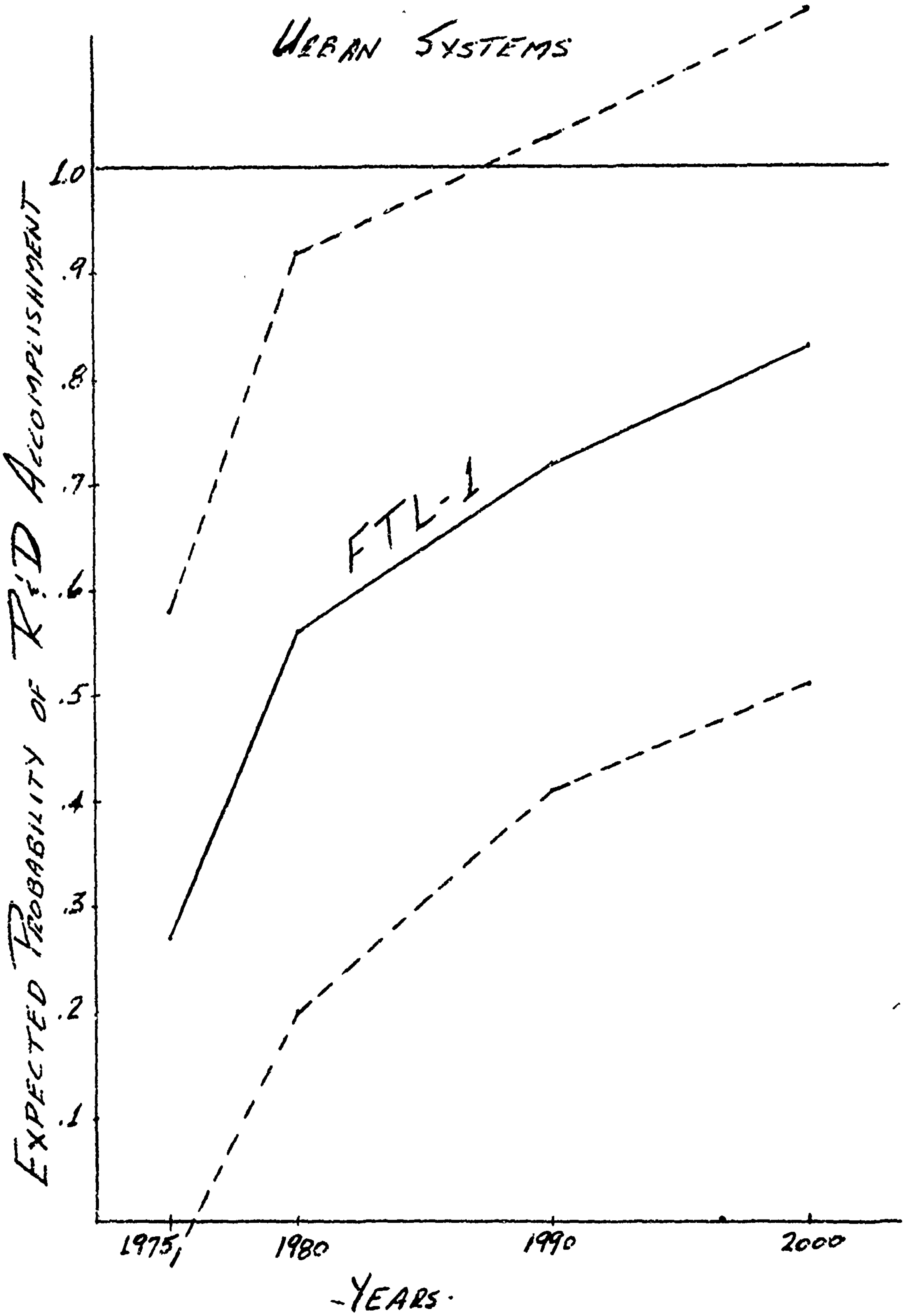
3-18

URBAN SYSTEM

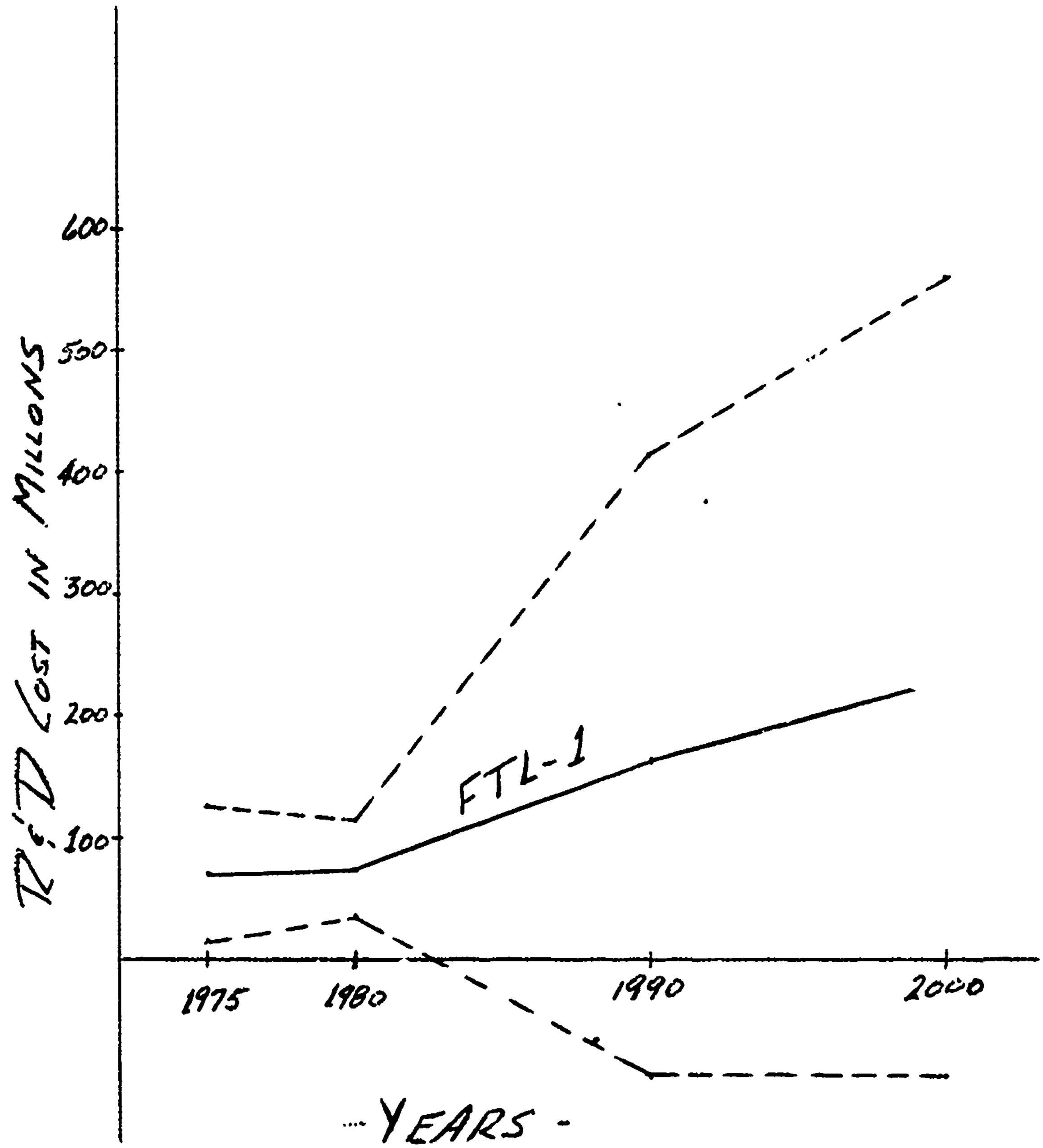


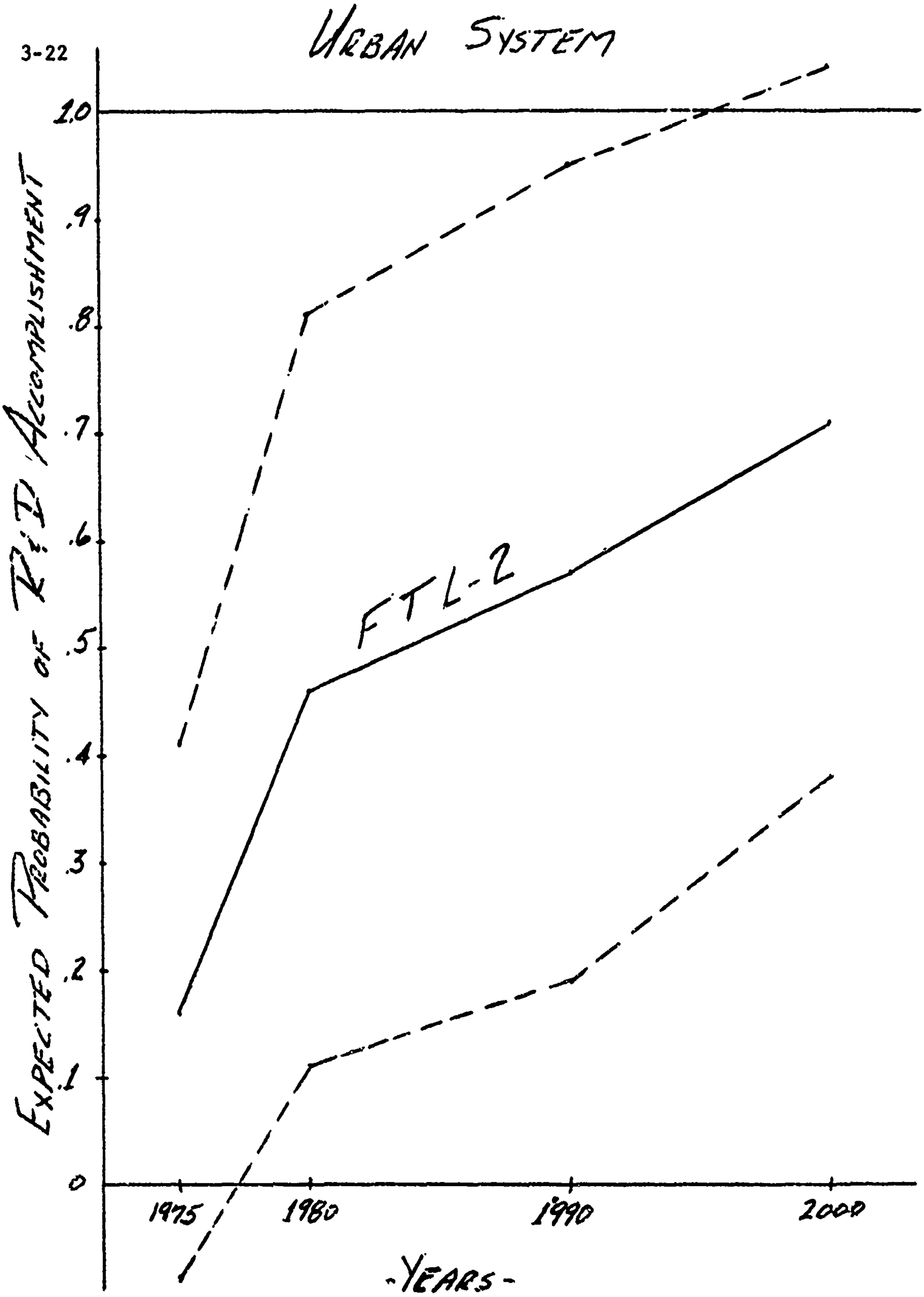
URBAN SYSTEM

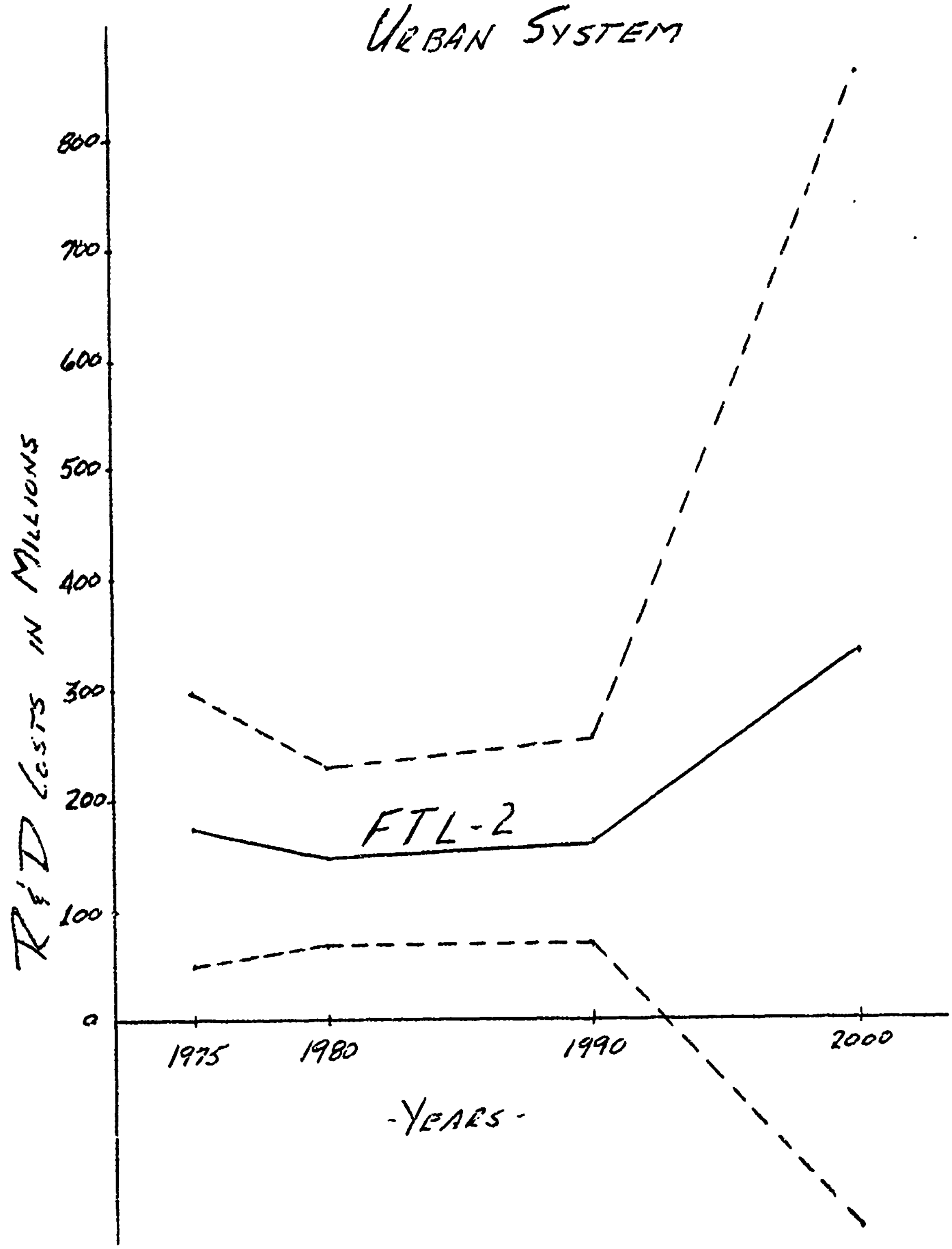



URBAN SYSTEMS
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
FTL-1
1975
1980
1990
2000
-YEARS-

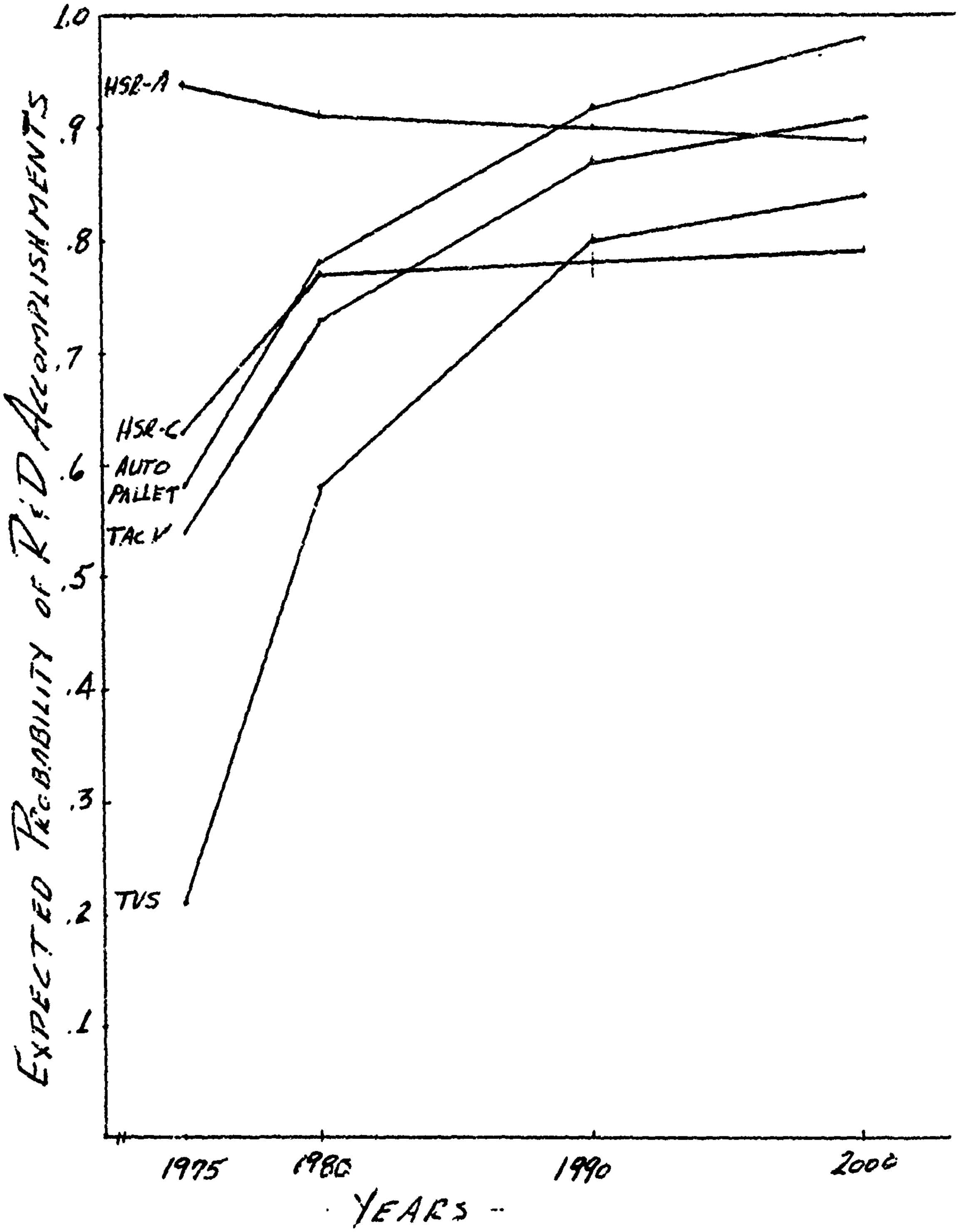
URBAN SYSTEMS



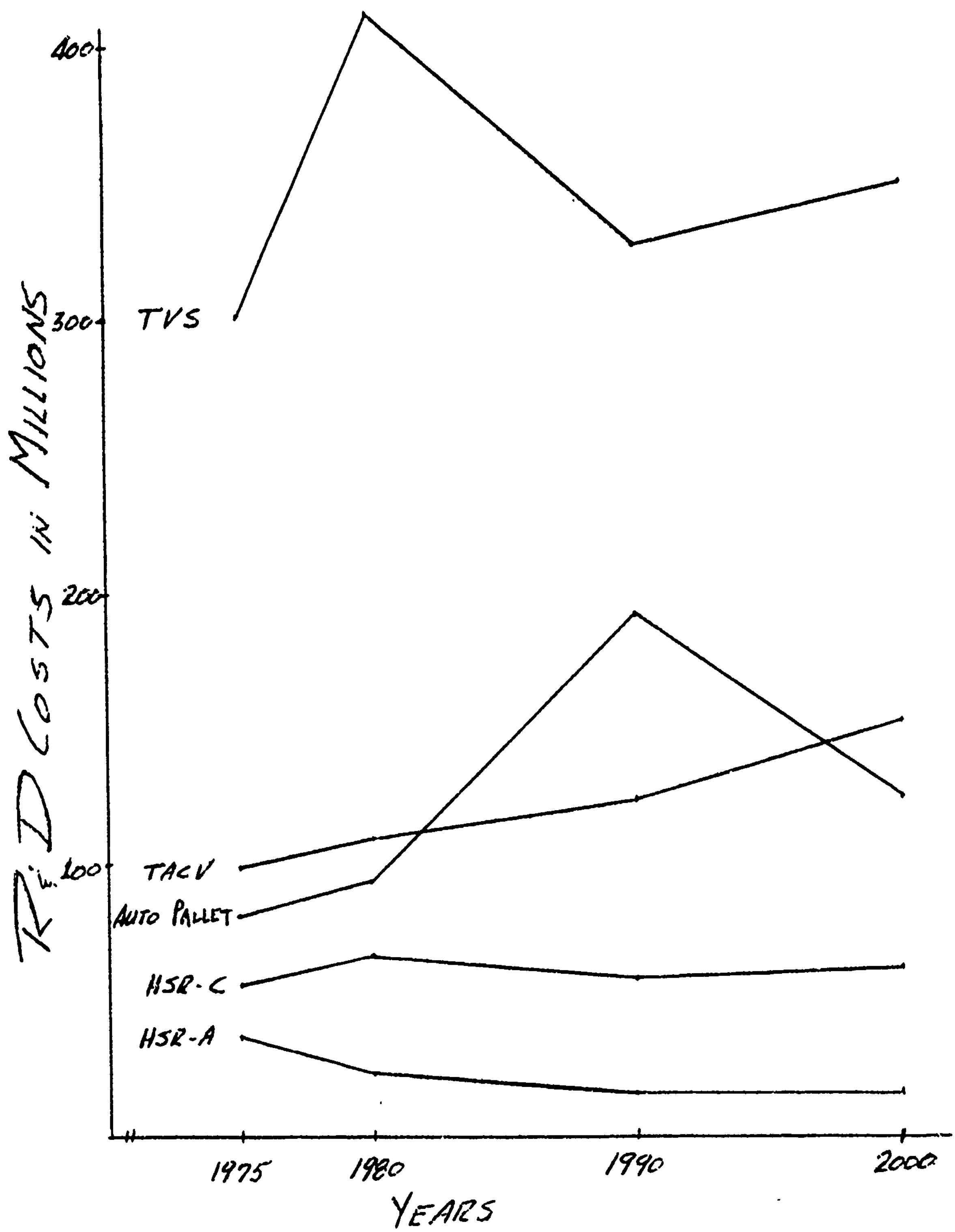

URBAN SYSTEM
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
FTL-2
1975
1980
1990
2000
-YEARS-

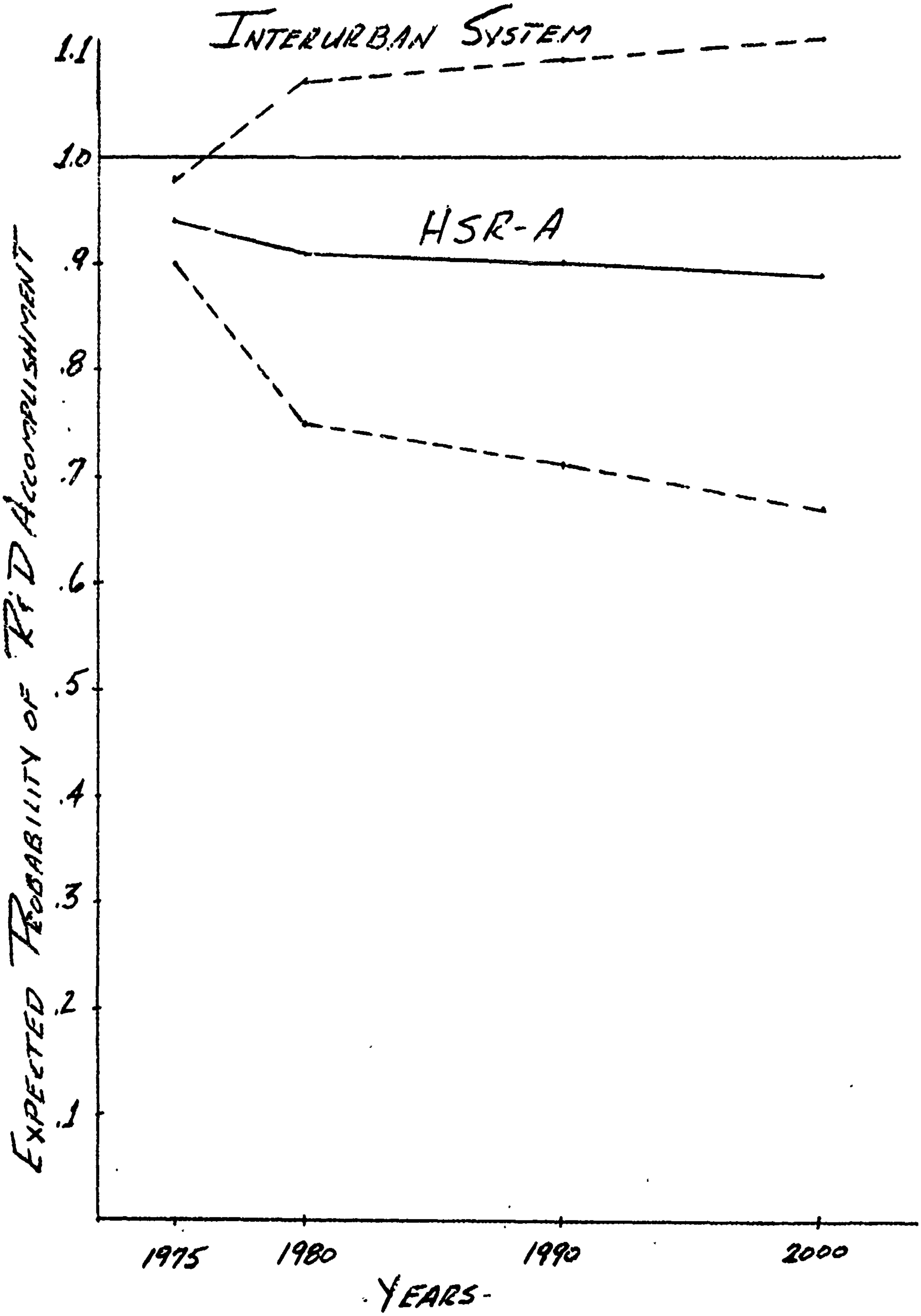

URBAN SYSTEM
R&D COSTS IN MILLIONS
800
700
600
500
400
300
200
100
0
FTL-2
1975
1980
1990
2000
-YEARS-

INTERURBAN SYSTEMS

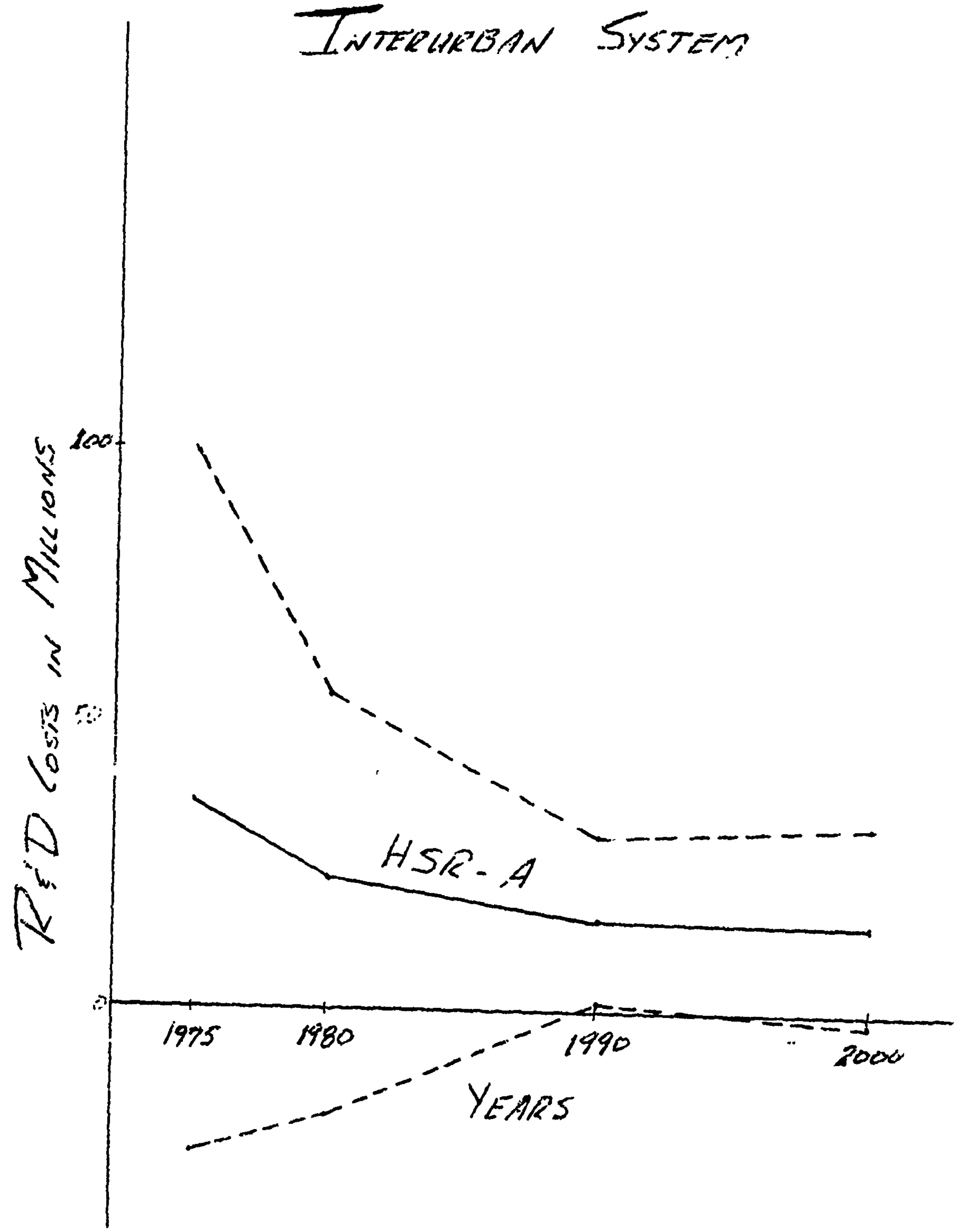


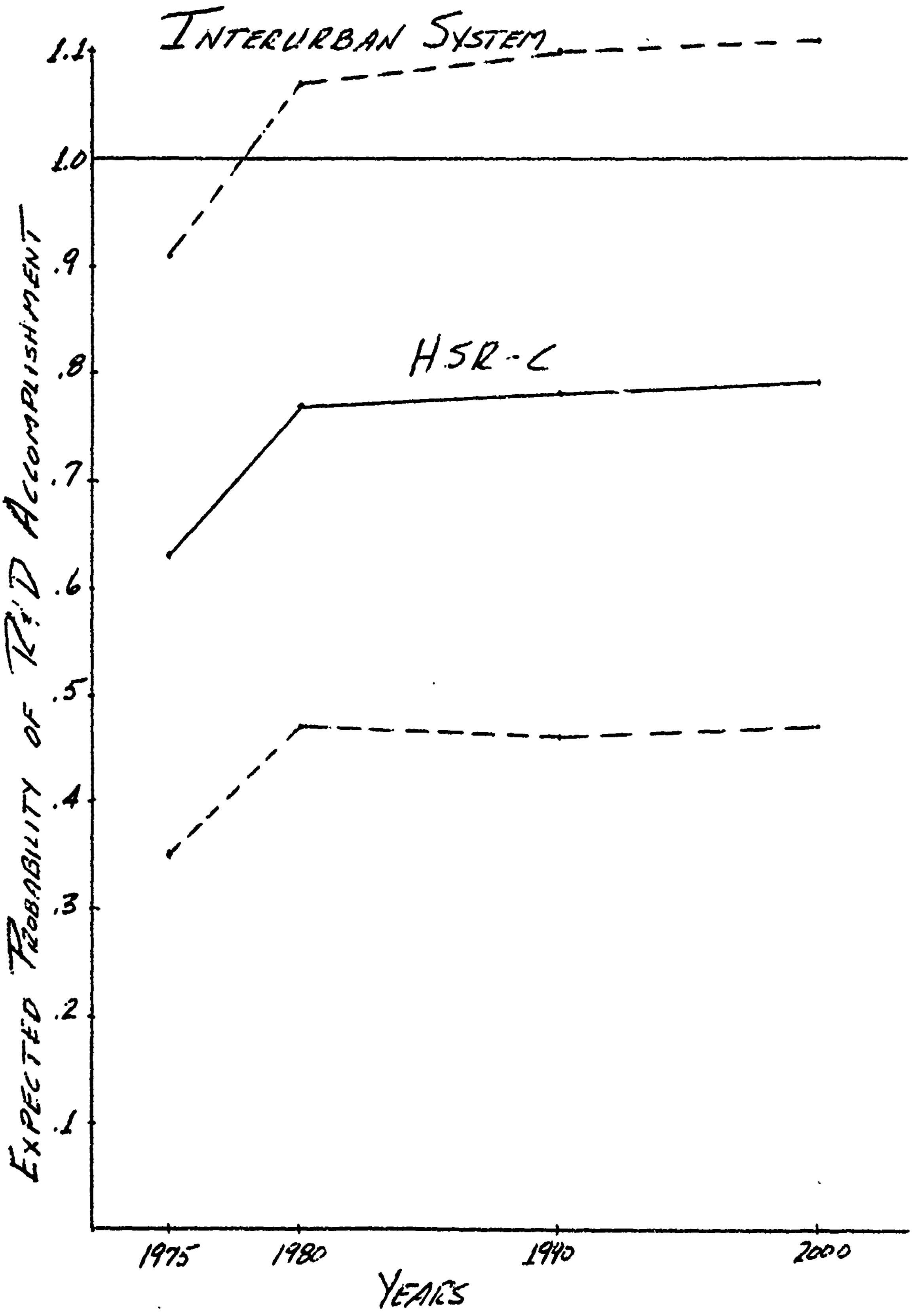
INTERURBAN SYSTEMS





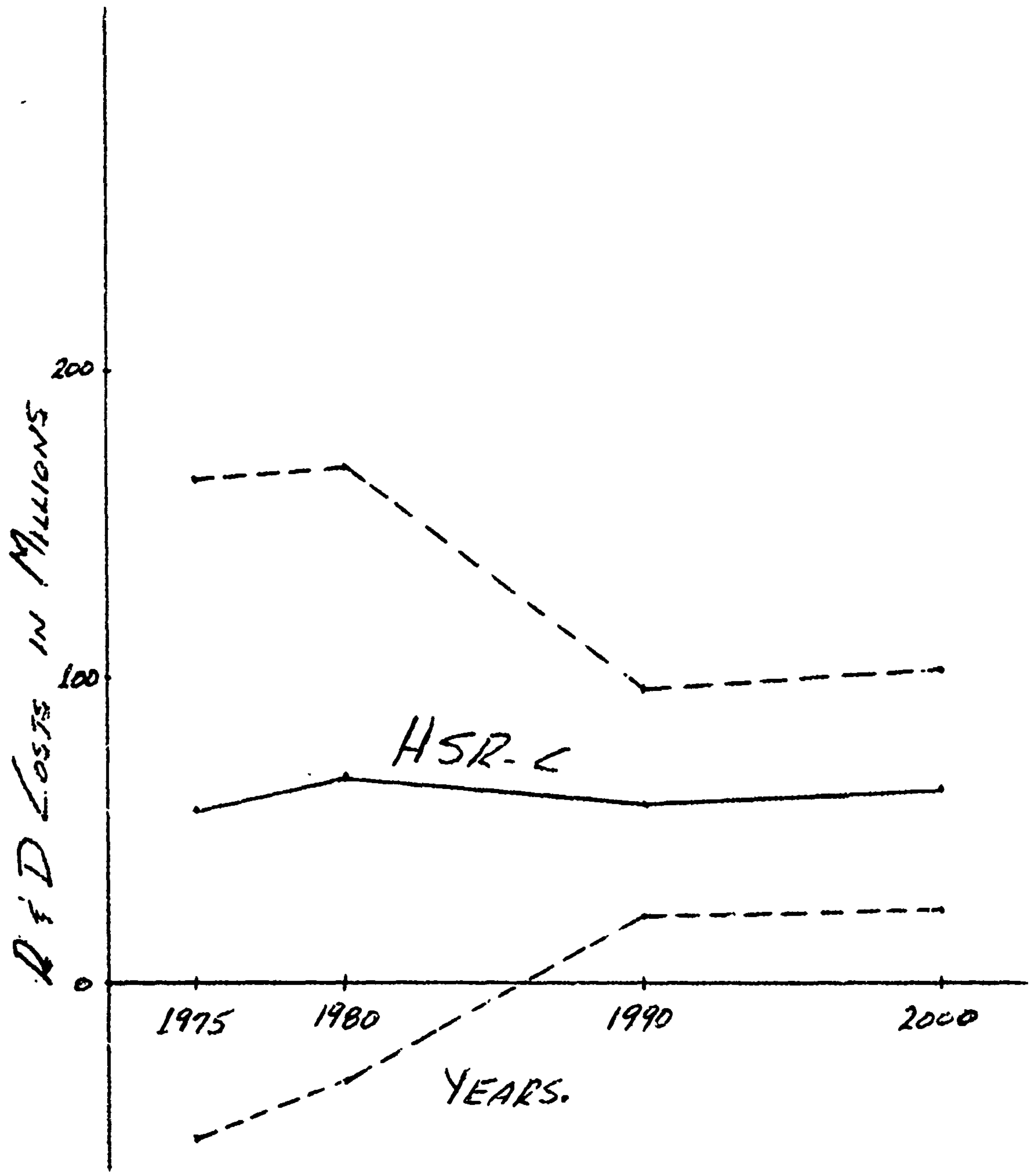
INTERURBAN SYSTEM
HSR-A
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
1975
1980
1990
2000
YEARS

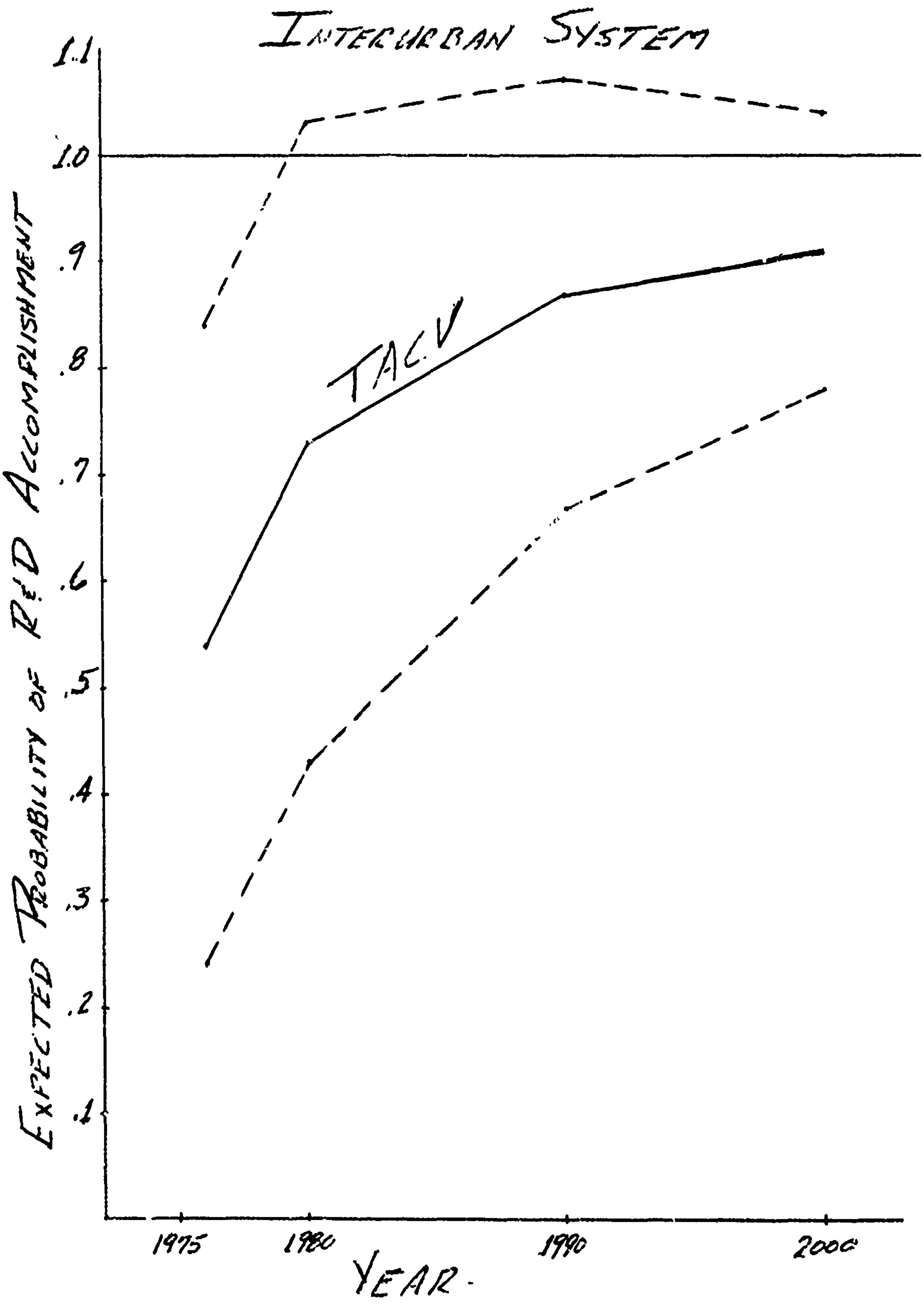

INTERURBAN SYSTEM
R&D COSTS IN MILLIONS
100
50
0
HSR-A
1975
1980
1990
2000
YEARS



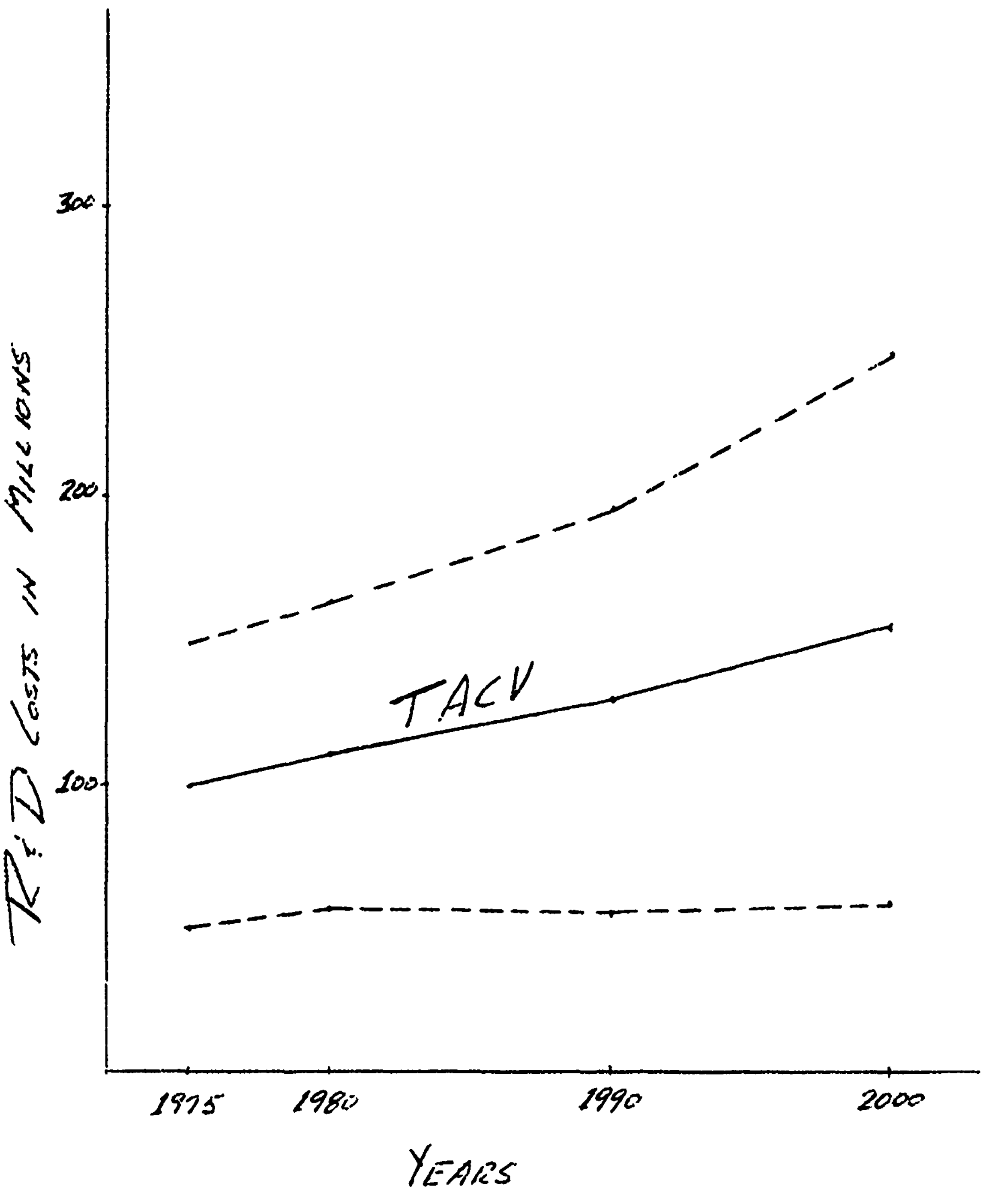
INTERURBAN SYSTEM
HSR-C
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
1975
1980
1990
2000
YEARS

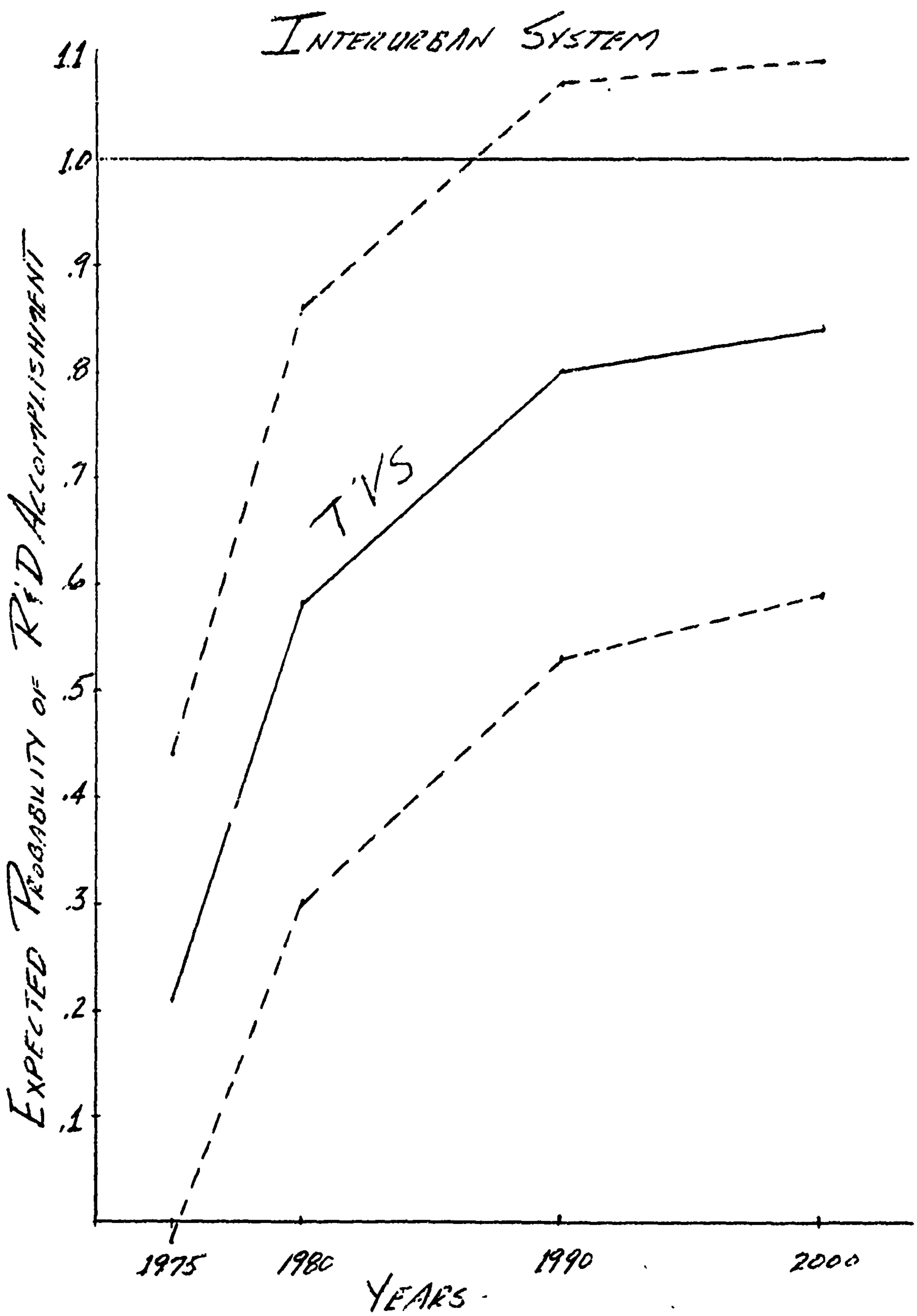
INTERURBAN SYSTEM



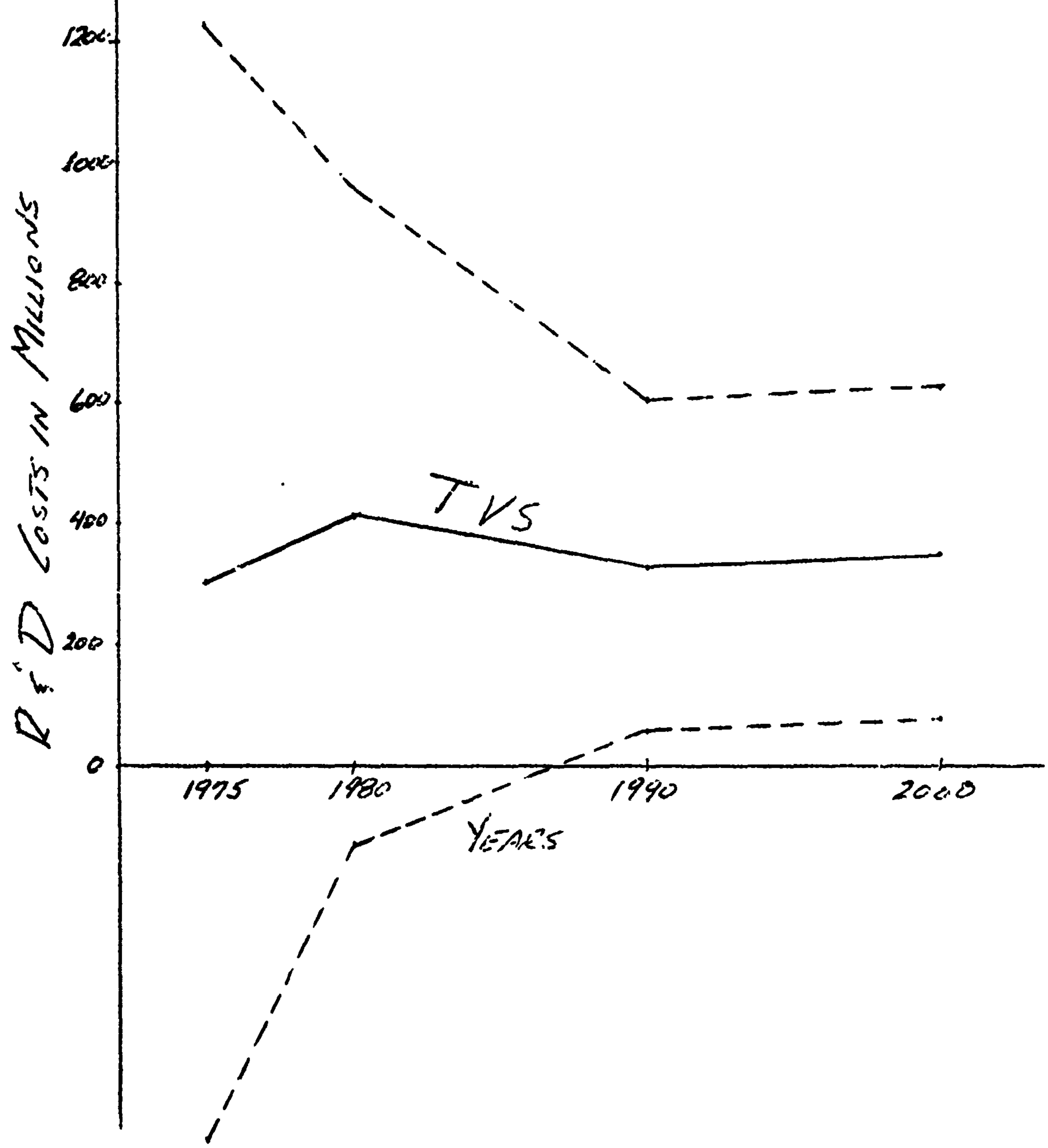

INTERURBAN SYSTEM
TACV
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1975
1980
1990
2000
YEAR

INTERURBAN SYSTEM

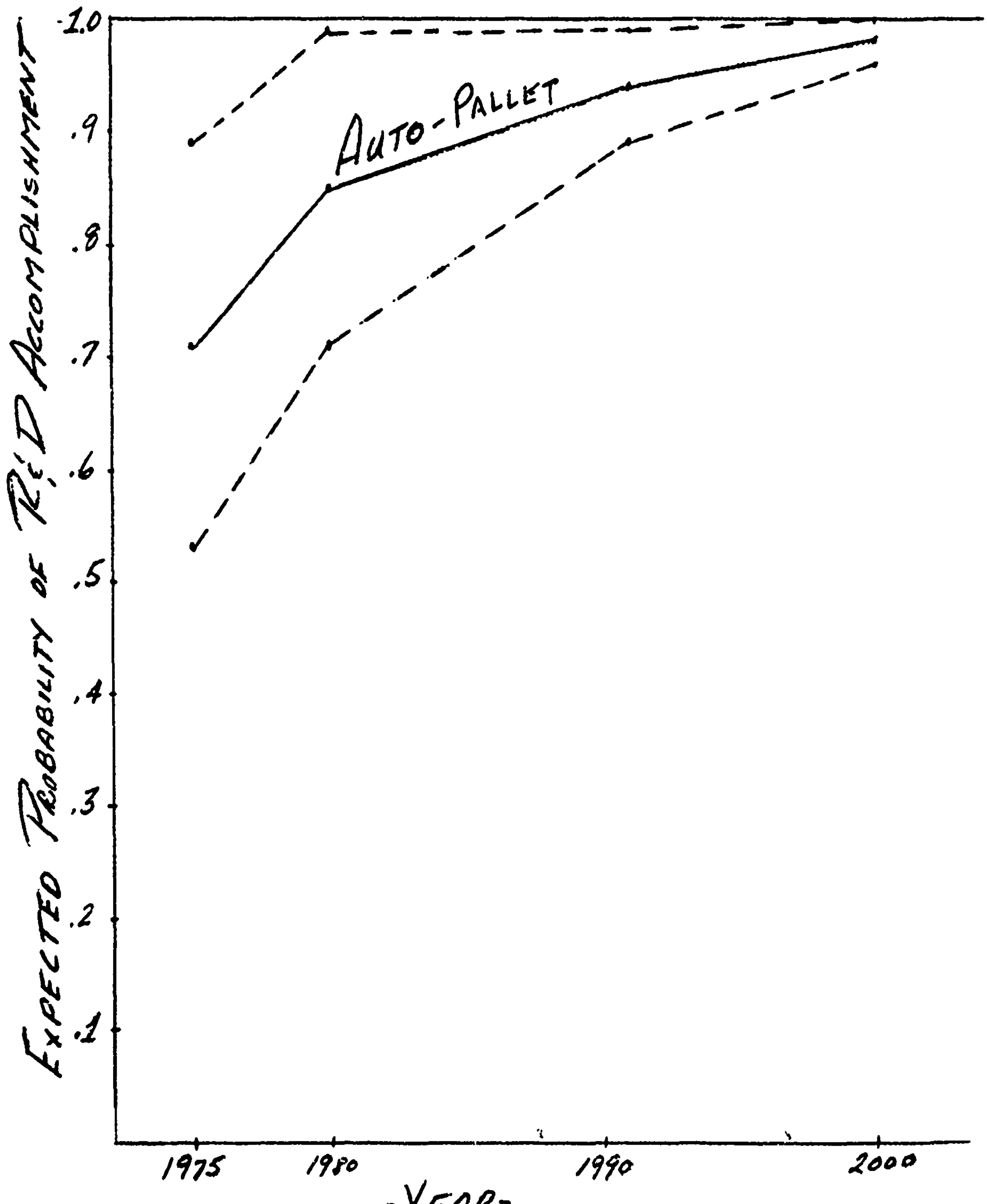


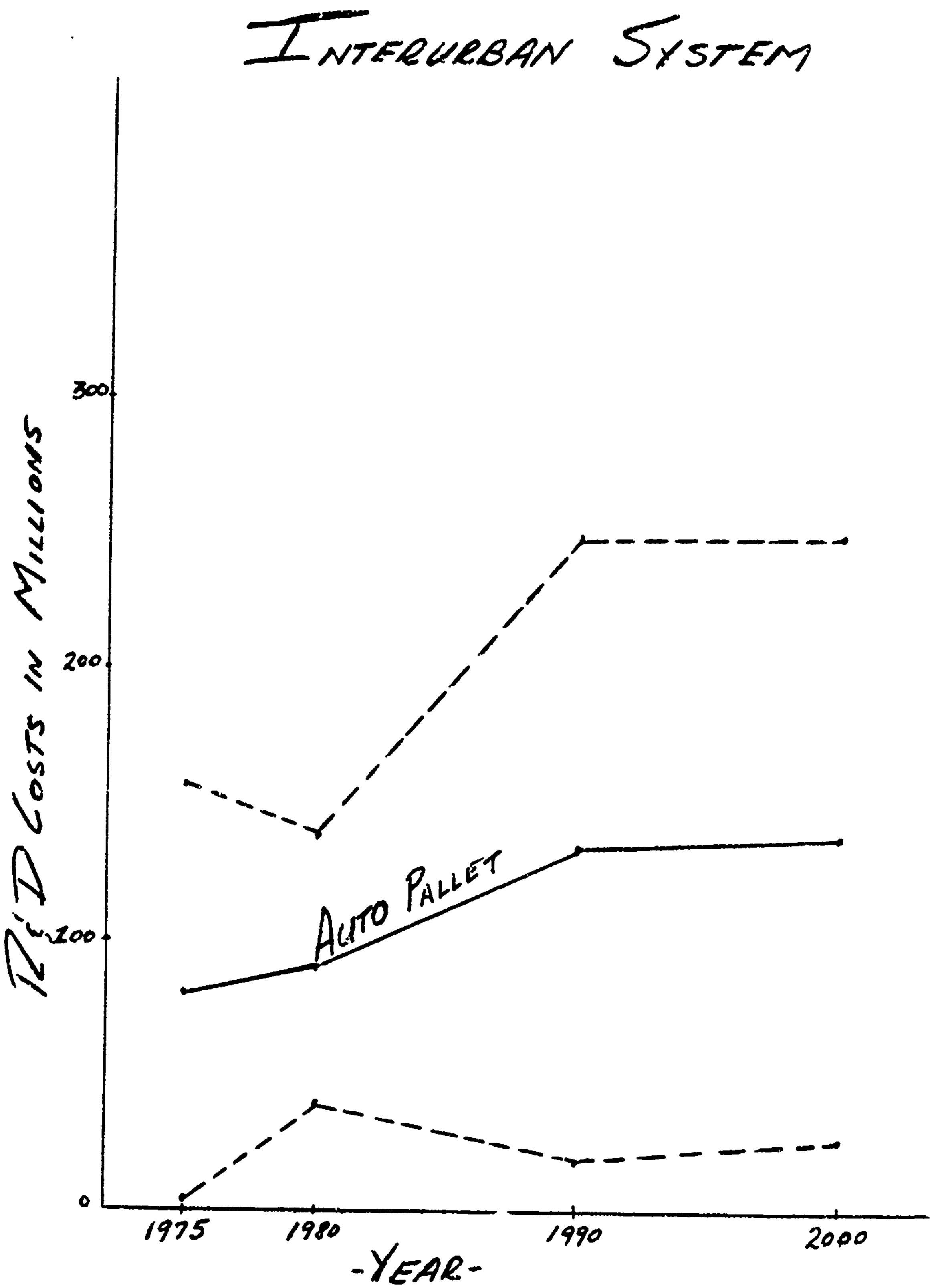

INTERURBAN SYSTEM
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
TVS
1975
1980
1990
2000
YEARS

INTERURBAN SYSTEMS

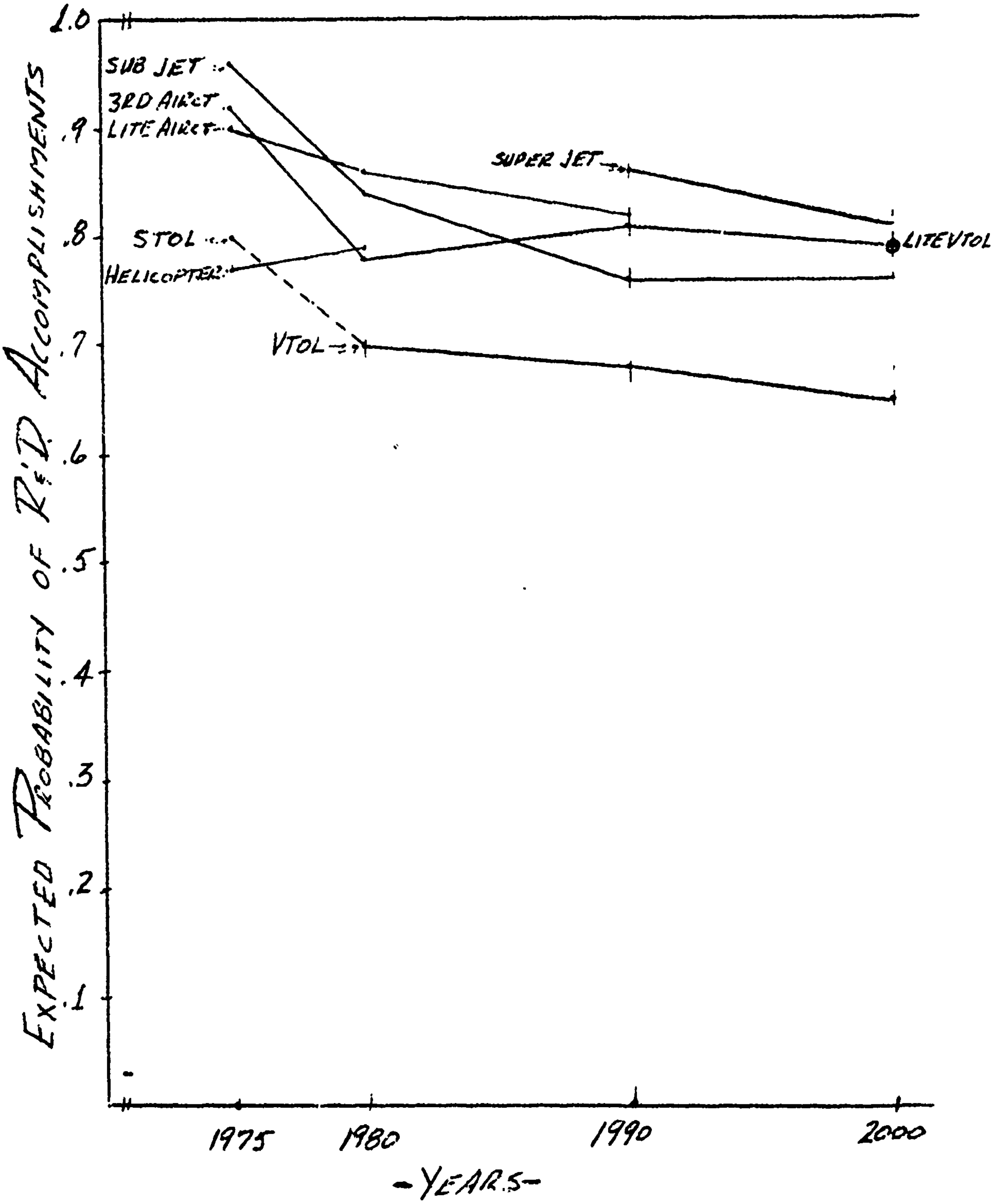


INTERURBAN SYSTEM

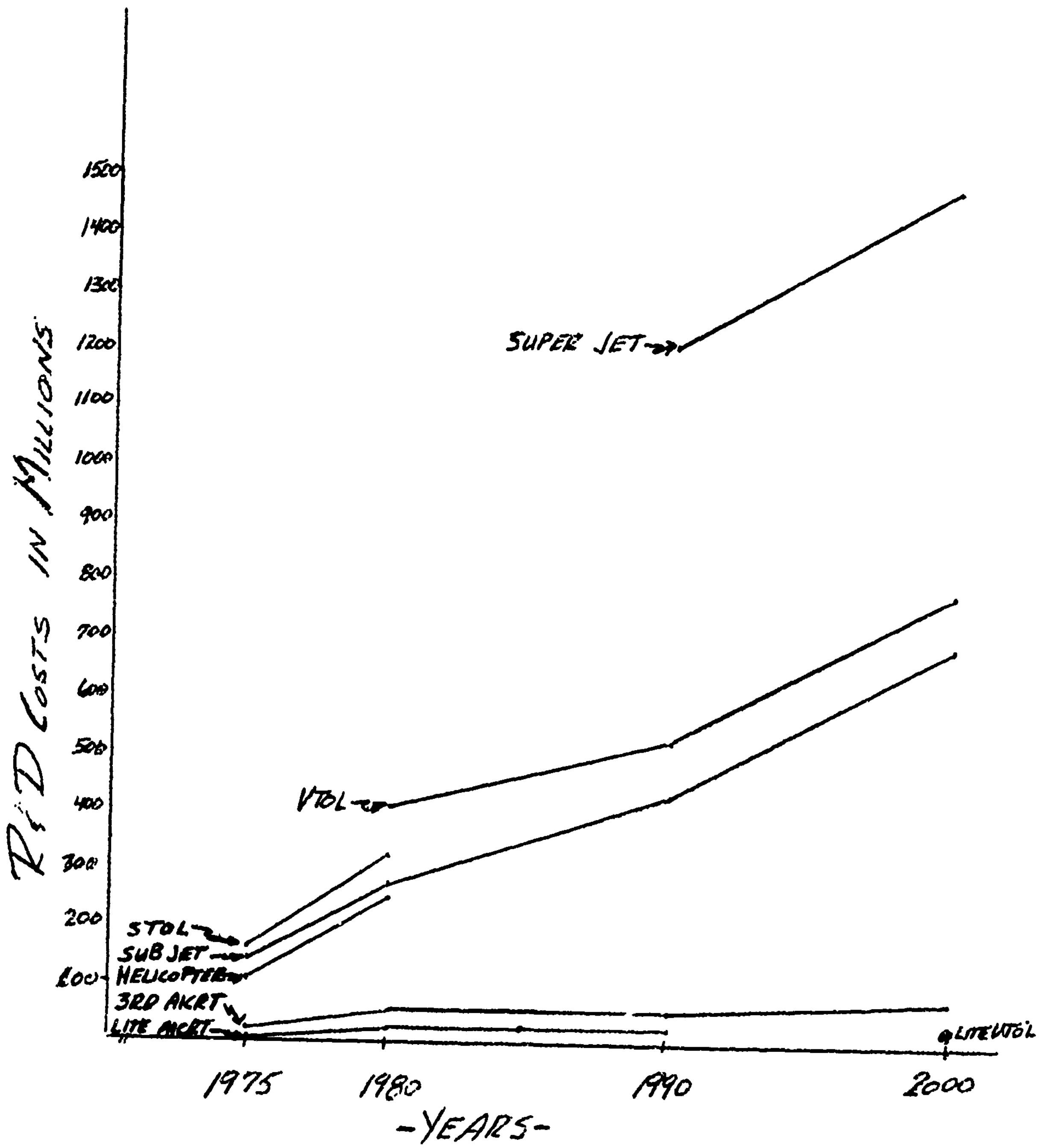


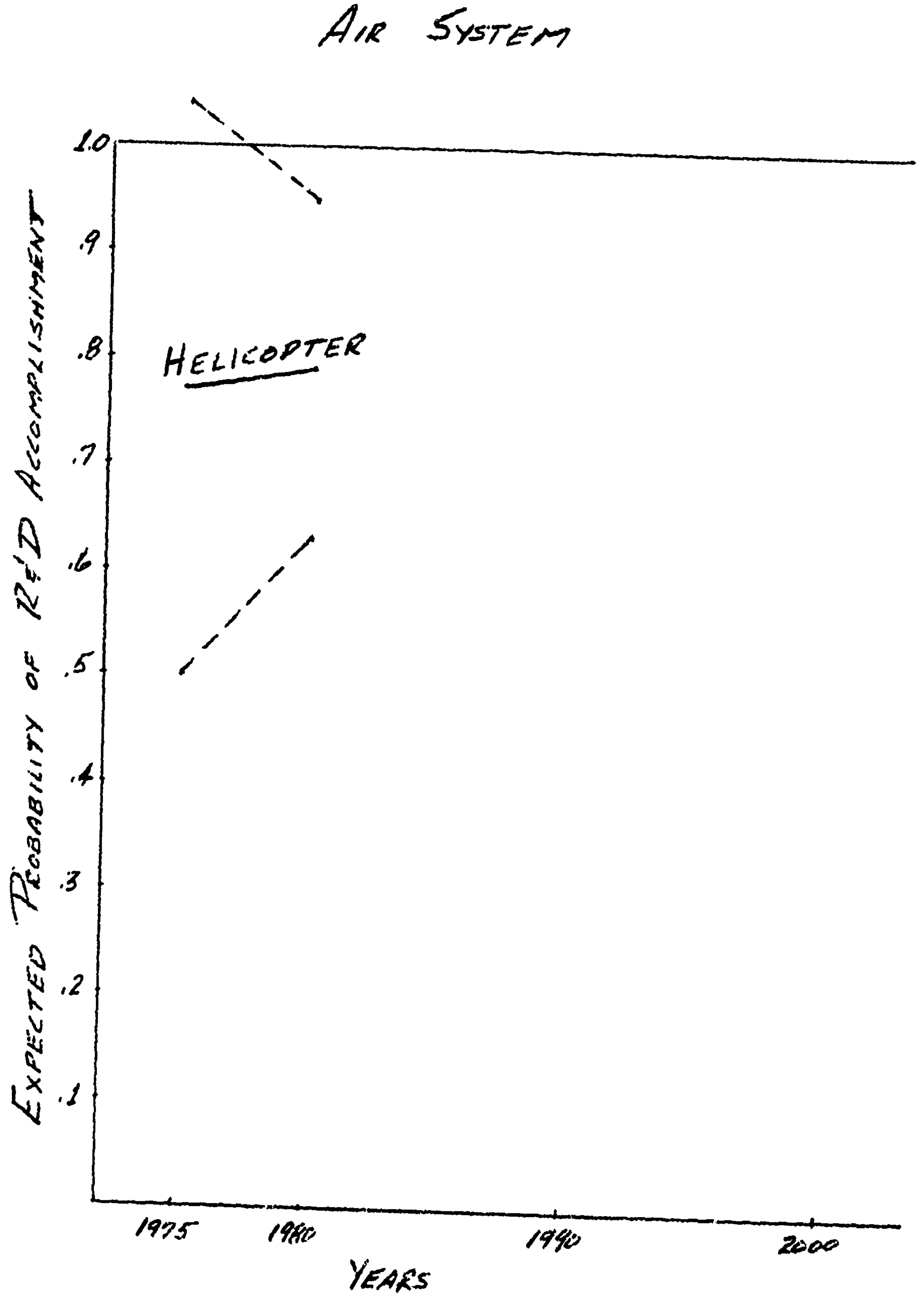

INTERURBAN SYSTEM
R&D COSTS IN MILLIONS
300
200
100
0
AUTO PALLET
1975
1980
1990
2000
-YEAR-

AIR SYSTEMS

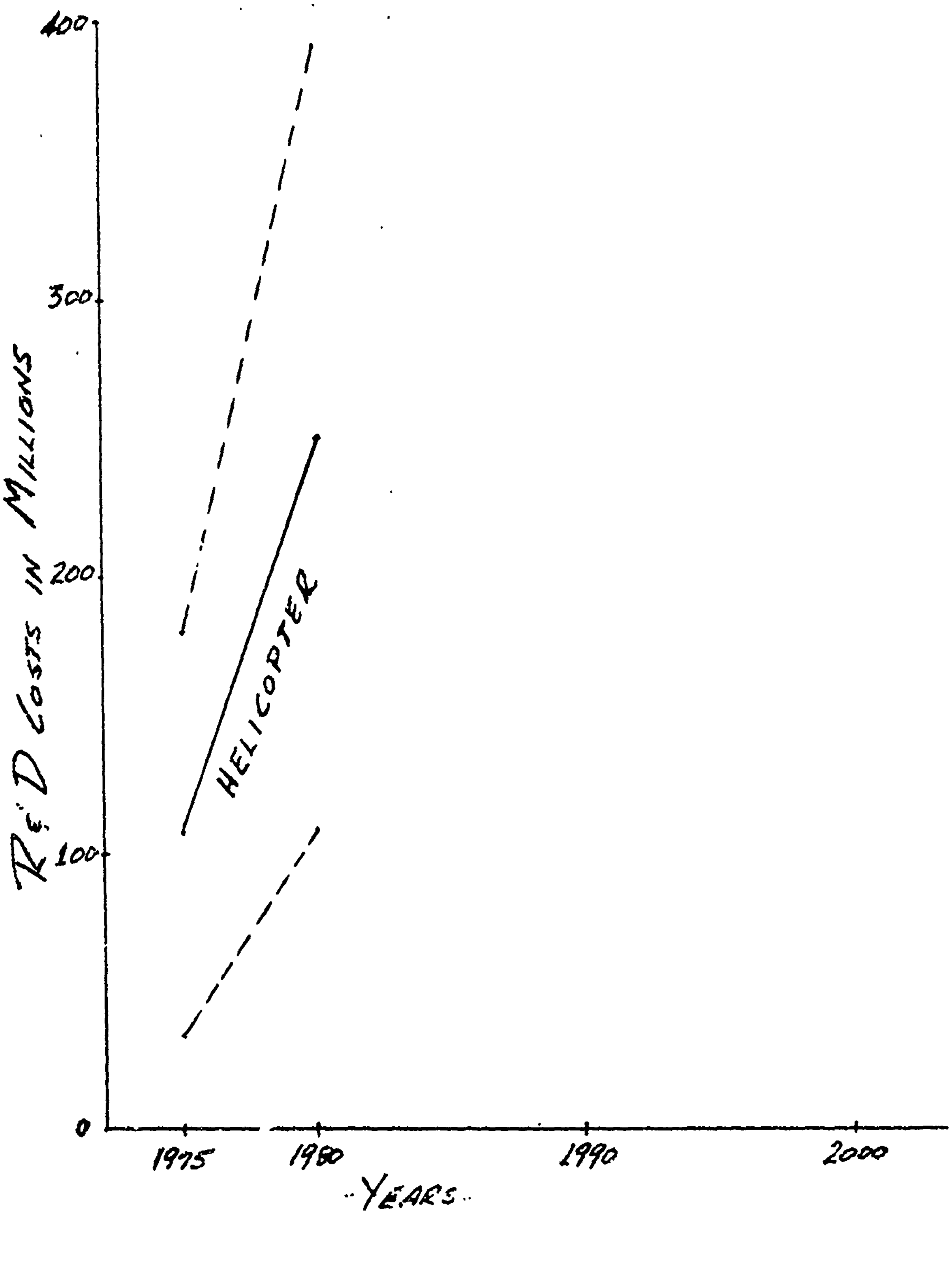

1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENTS
SUB JET
3RD AIRCT
LITE AIRCT
SUPER JET
STOL
HELICOPTER
LITEVTOL
VTOL
1975
1980
1990
2000
-YEARS-

AIR SYSTEMS

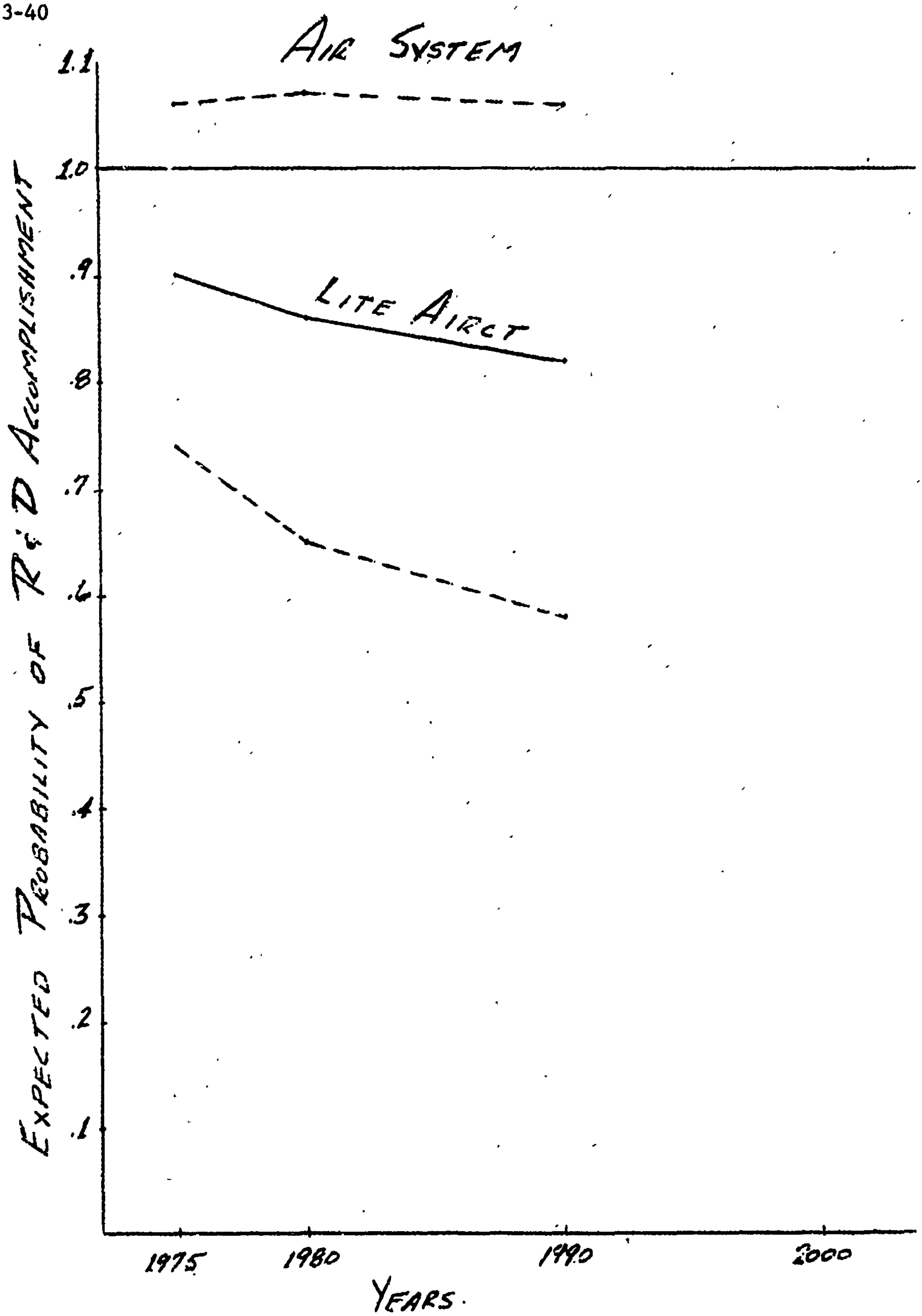

R & D COSTS IN MILLIONS
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
SUPER JET
VTOL
STOL
SUB JET
HELICOPTER
3RD ACRT
LITE ACRT
LITE VTOL
1975
1980
1990
2000
-YEARS-


AIR SYSTEM
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
HELICOPTER
1975
1980
1990
2000
YEARS

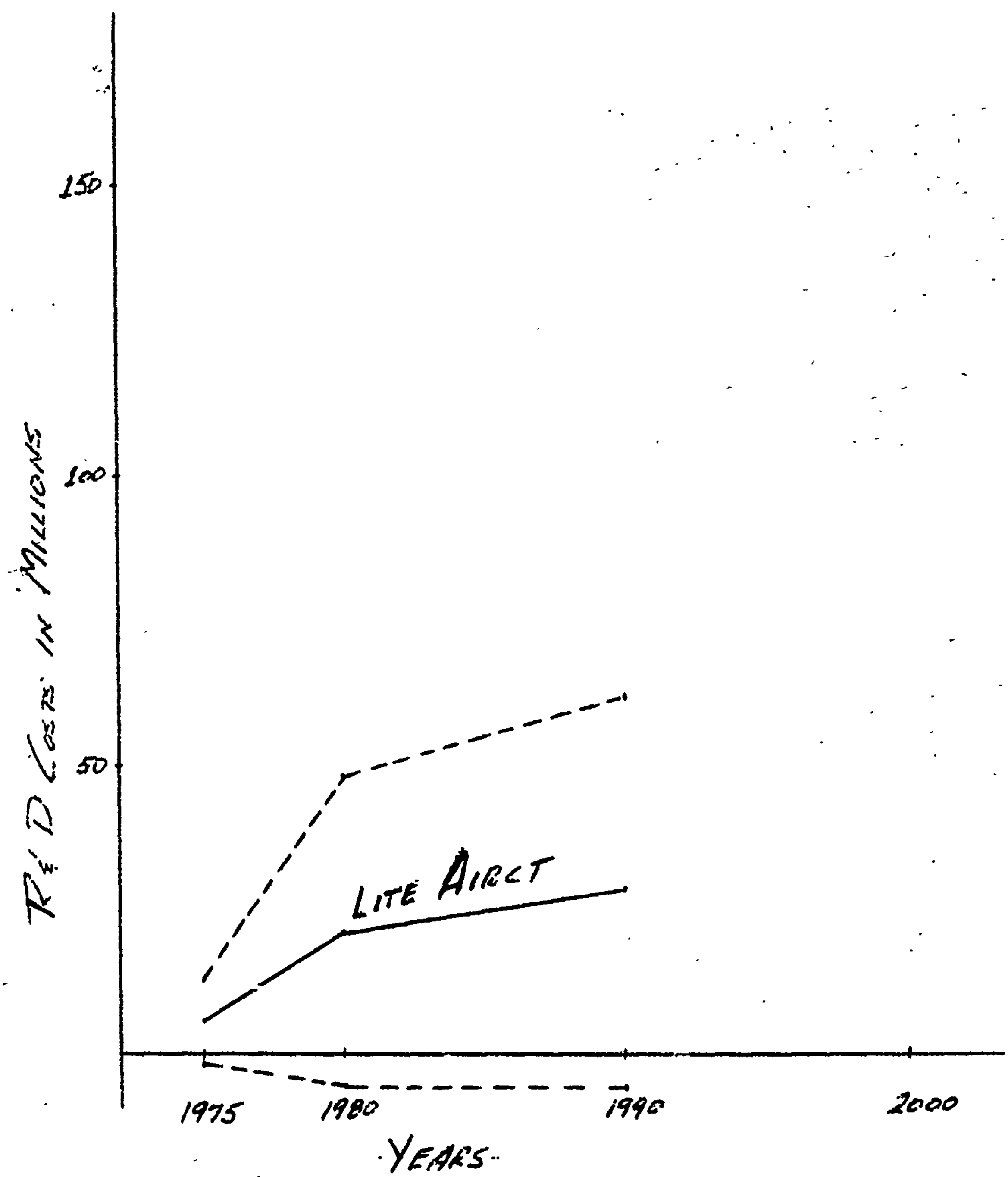
AIR SYSTEM-



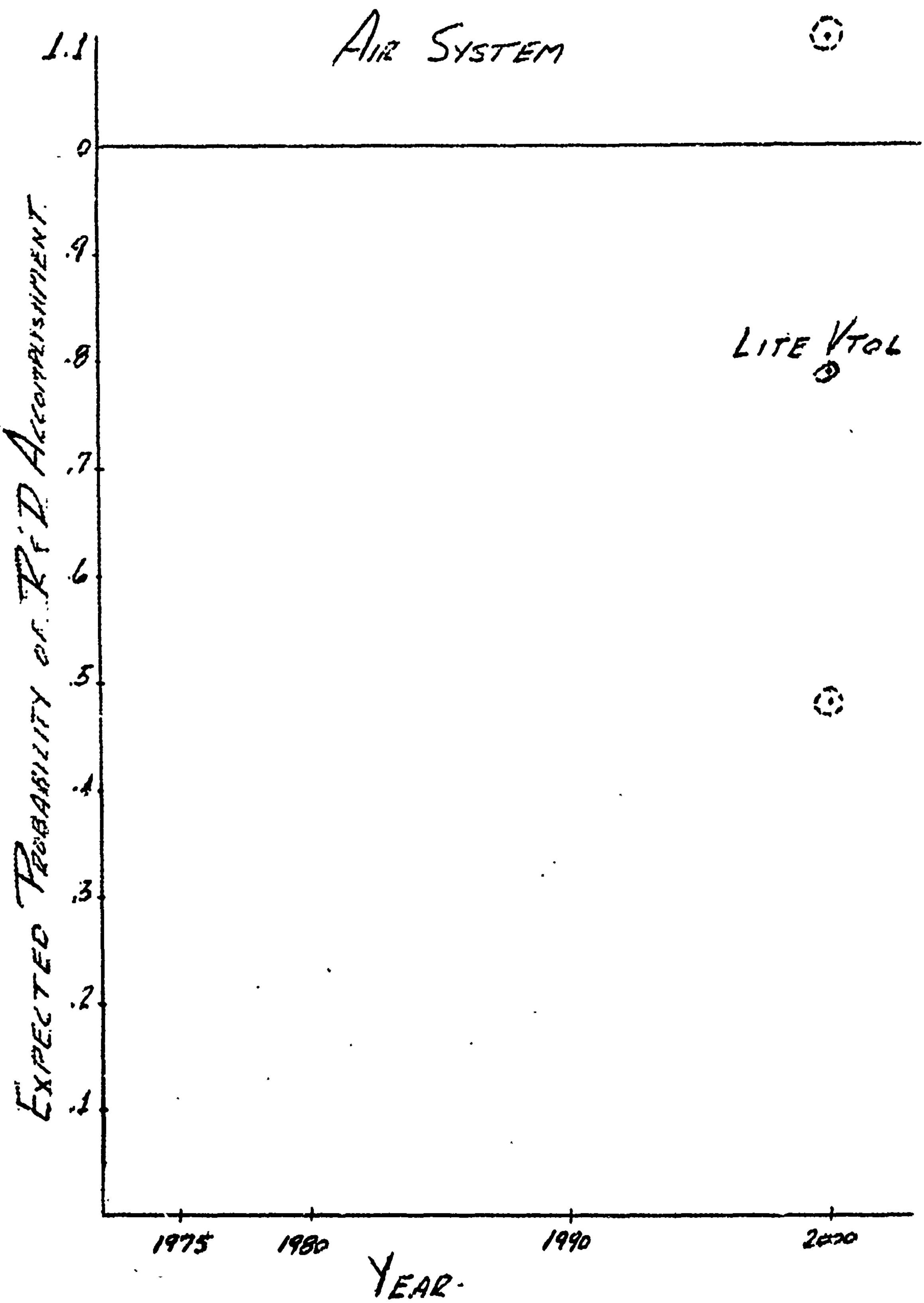
R&D COSTS IN MILLIONS
400
300
200
100
0
HELICOPTER
1975
1980
1990
2000
YEARS


AIR SYSTEM
LITE AIRCT
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
1975
1980
1990
2000
YEARS

AIR SYSTEM

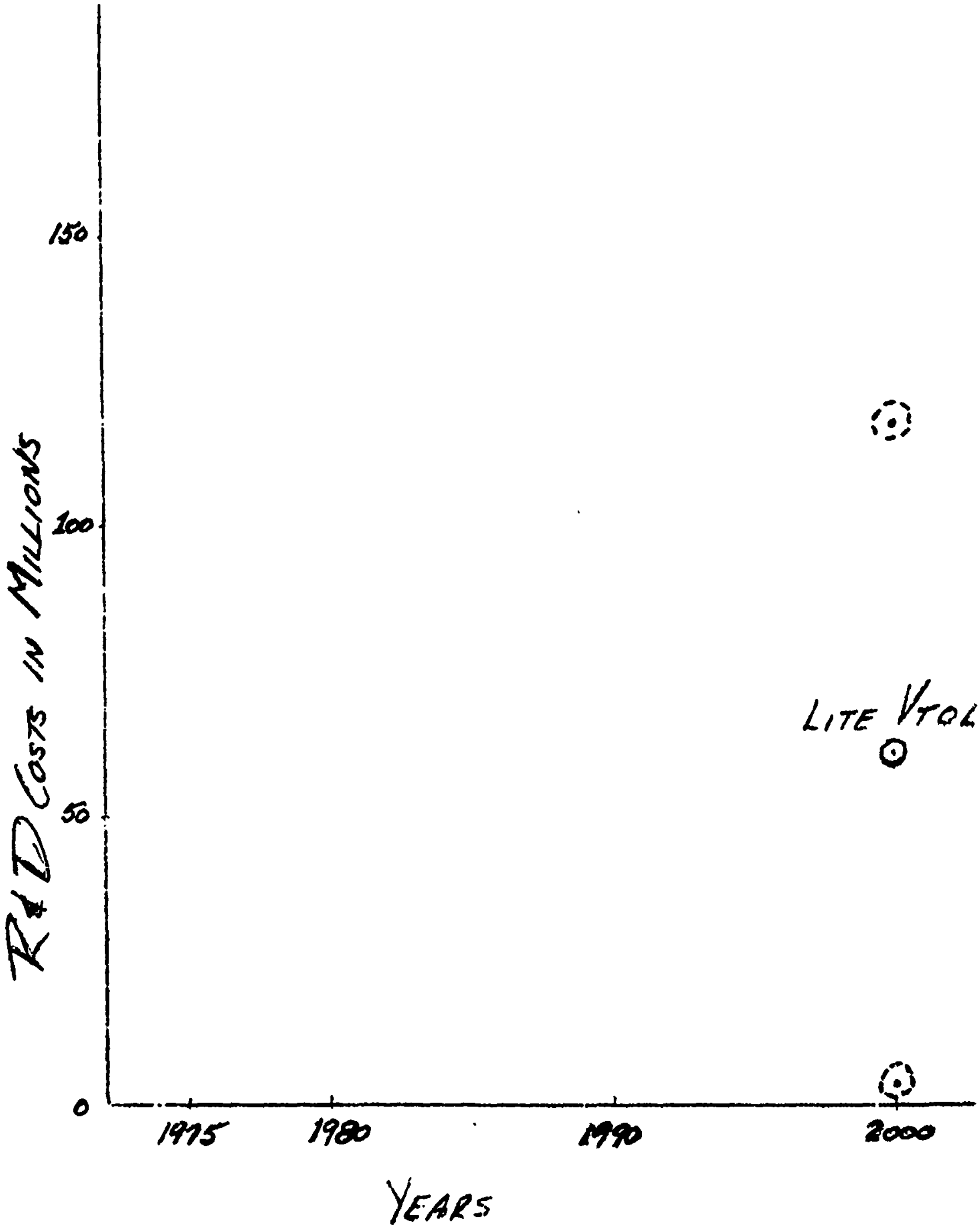


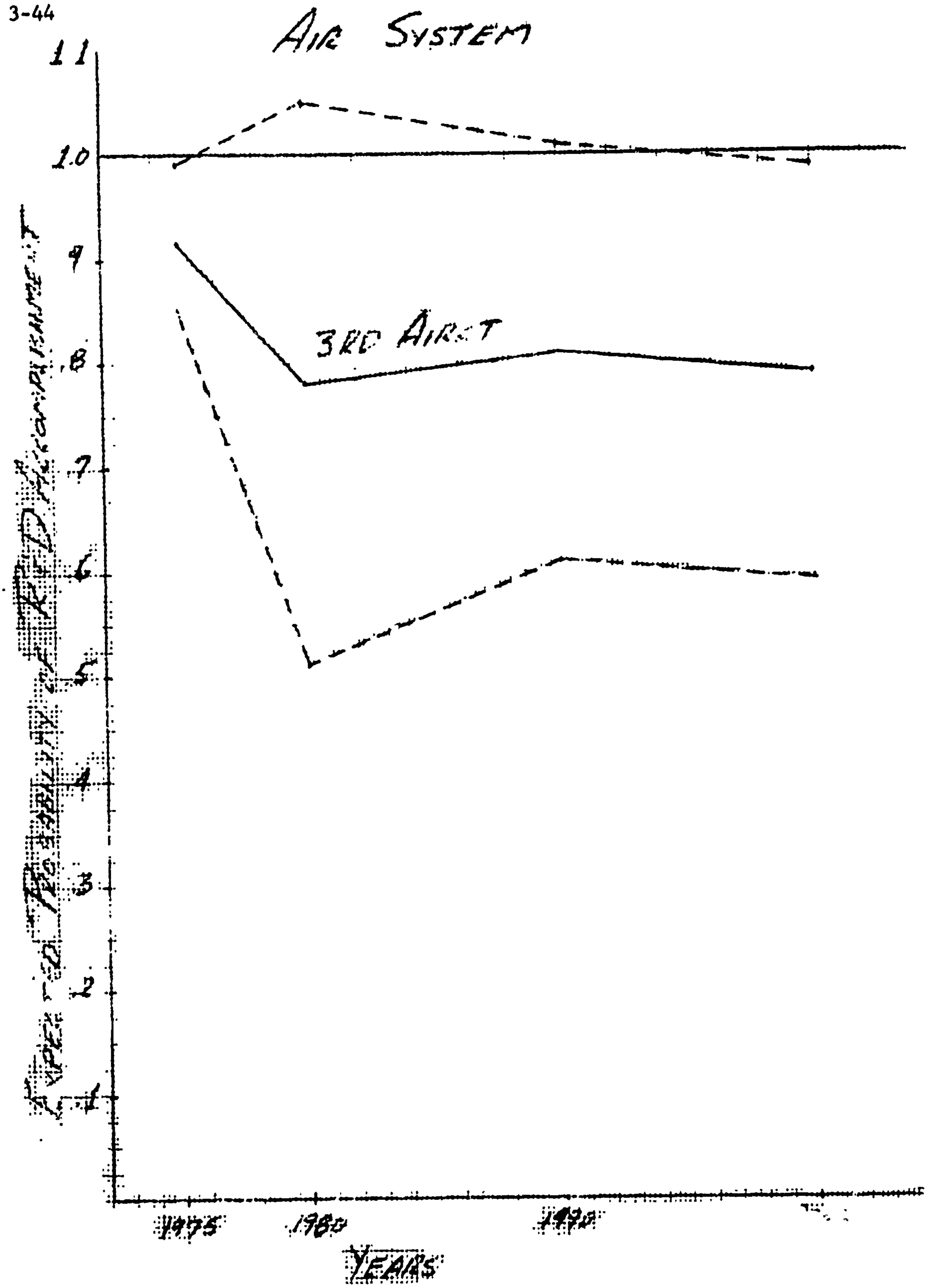
150
100
50
R&D COSTS IN MILLIONS
LITE AIRCT
1975
1980
1990
2000
YEARS



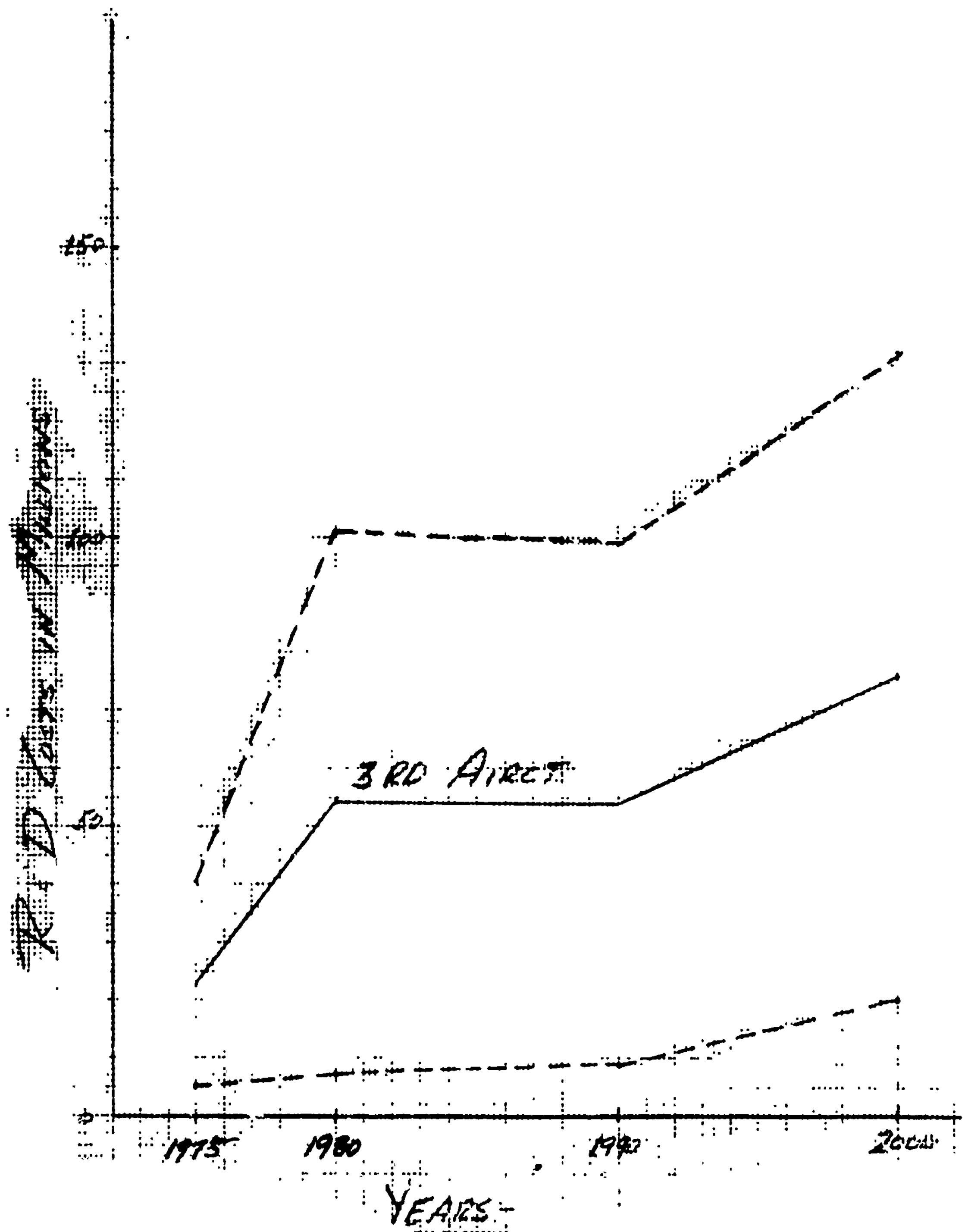
AIR SYSTEM
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
LITE VTOL
1975
1980
1990
2000
YEAR

AIR SYSTEM

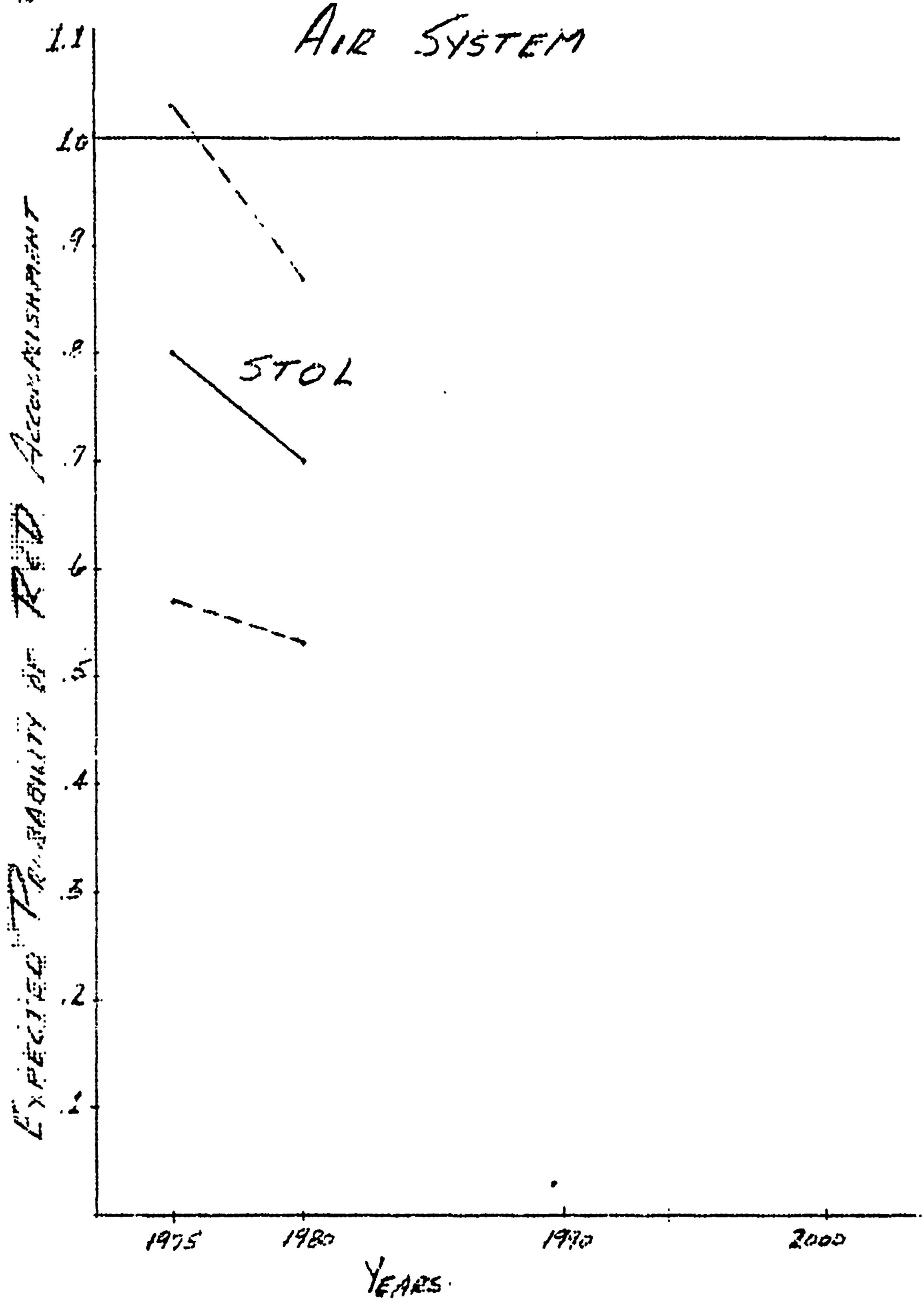

R&D COSTS IN MILLIONS
150
100
50
0
LITE VTOL
1975
1980
1990
2000
YEARS


AIR SYSTEM
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
3RD AIRCT
1975
1980
1990
YEARS

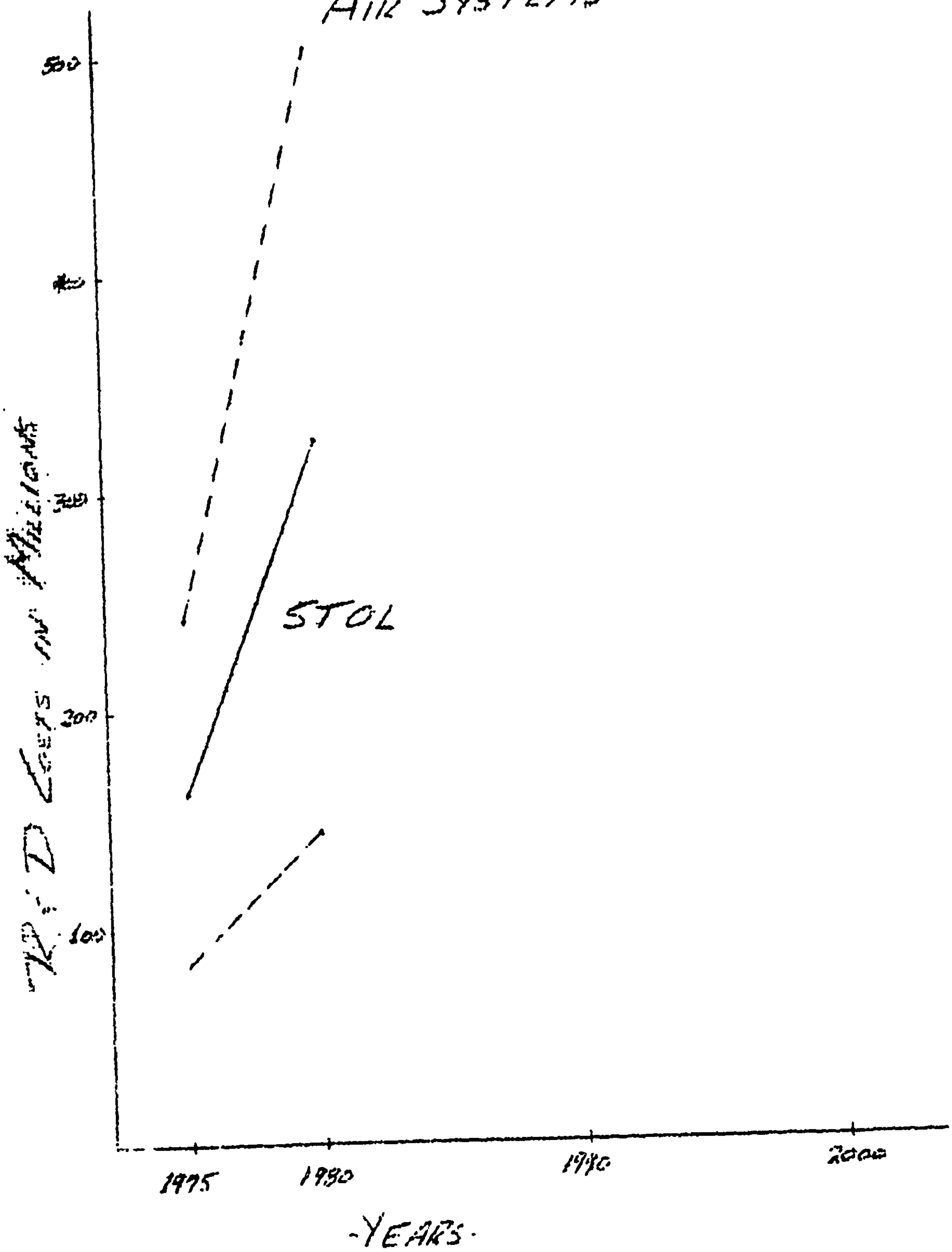
AIR SYSTEM

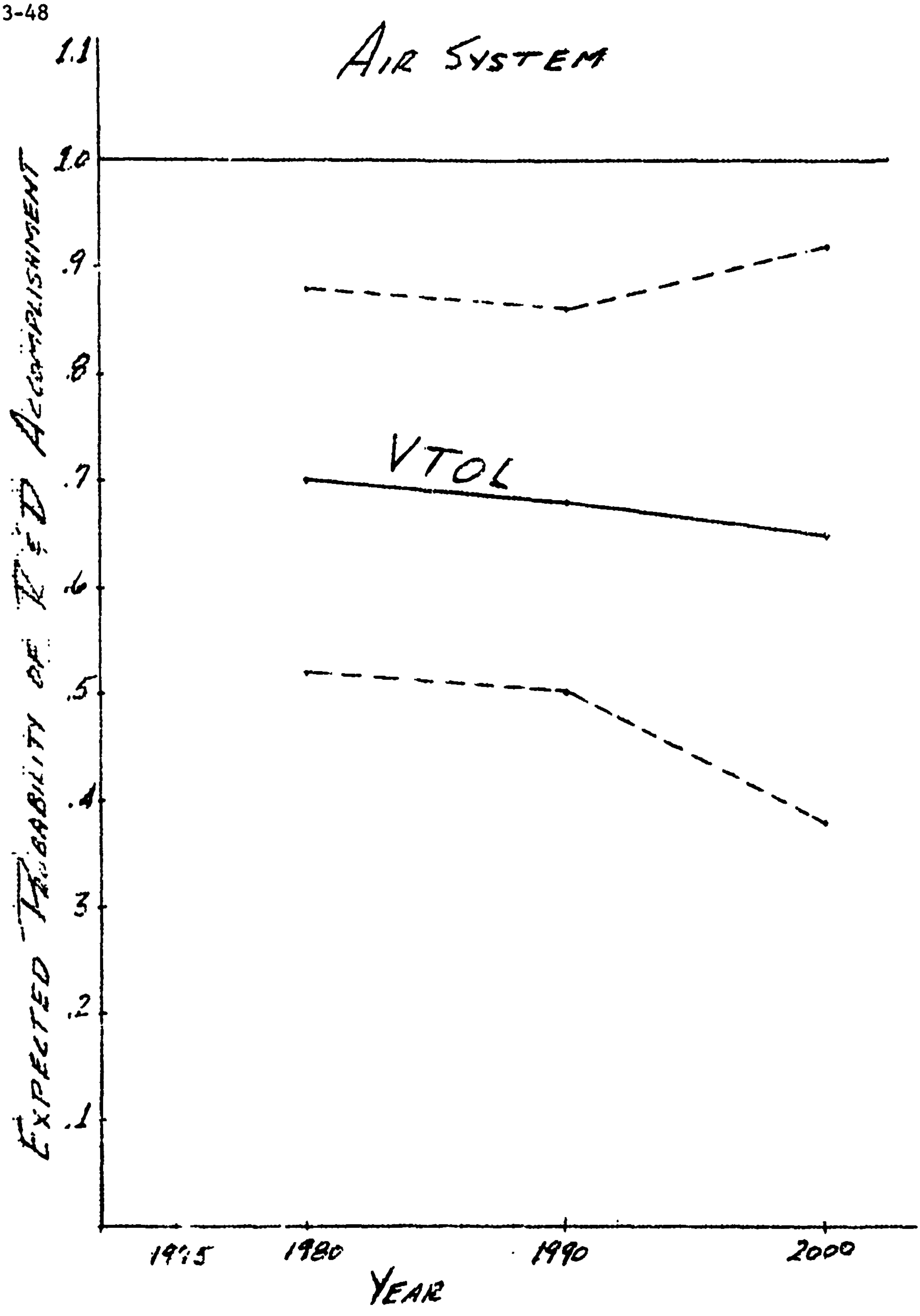


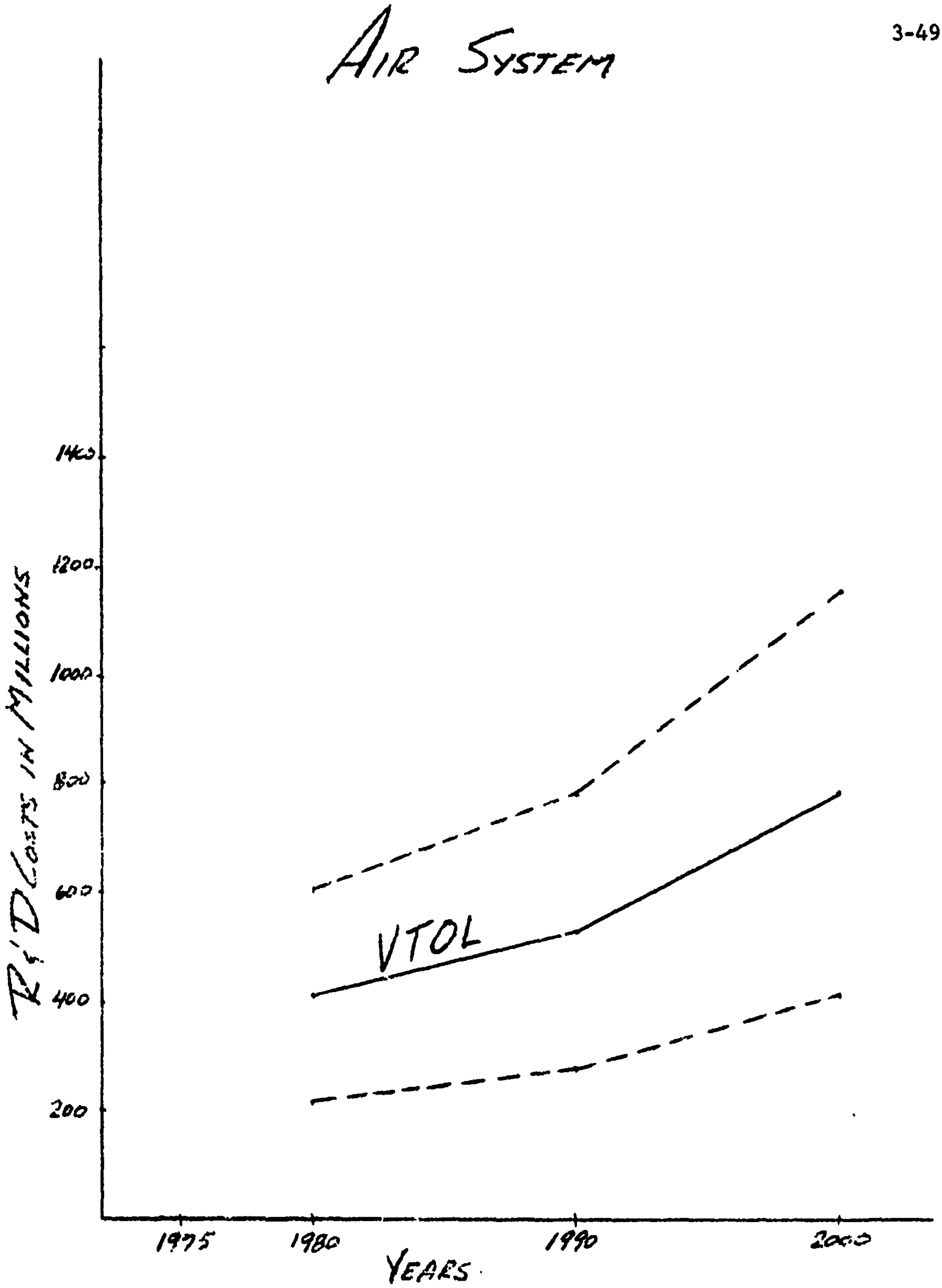
R+D COSTS IN $ MILLIONS
150
100
50
0
3RD AIRCFT
1975
1980
1990
2000
YEARS

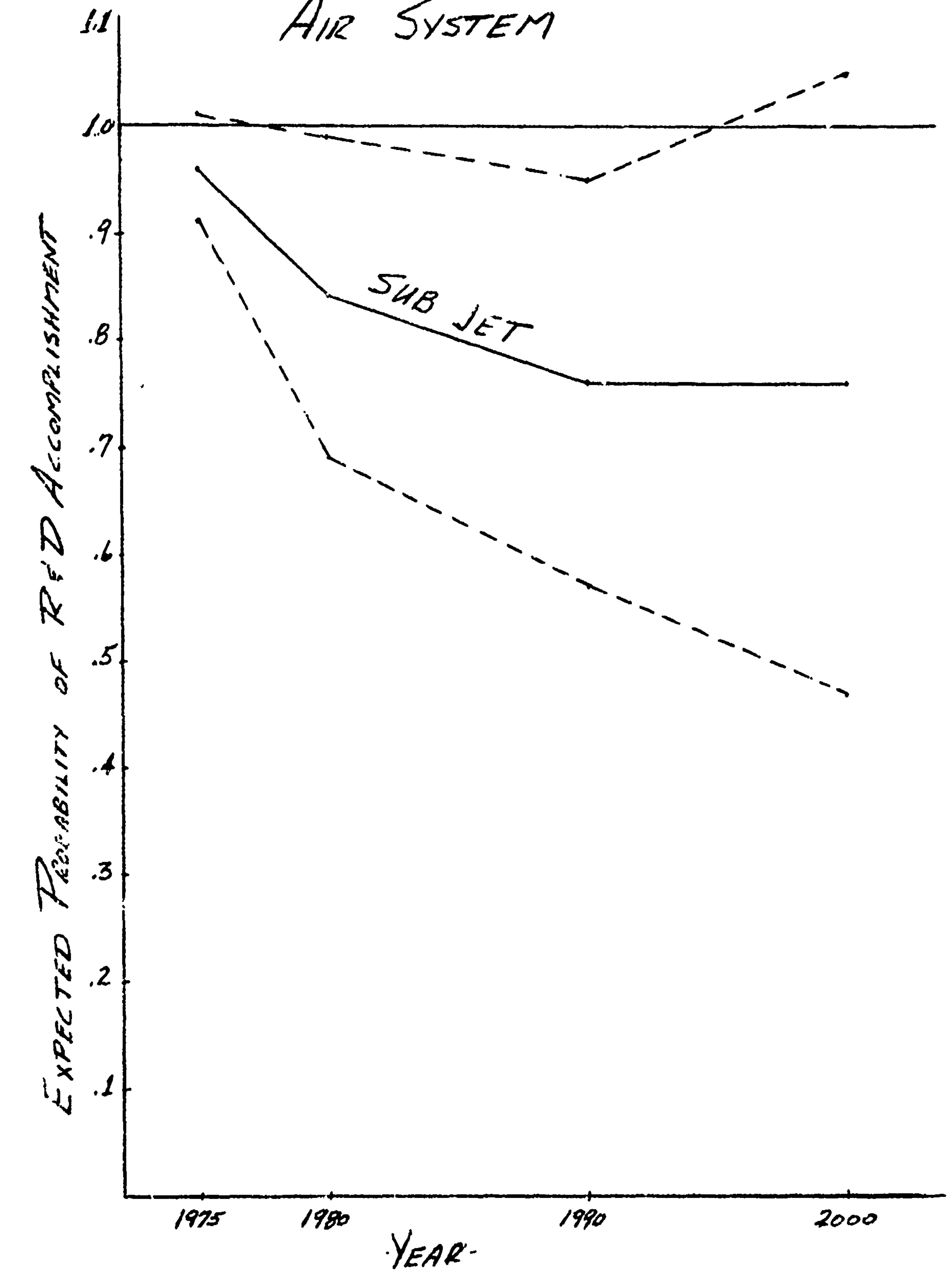

AIR SYSTEM
STOL
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1975
1980
1990
2000
YEARS

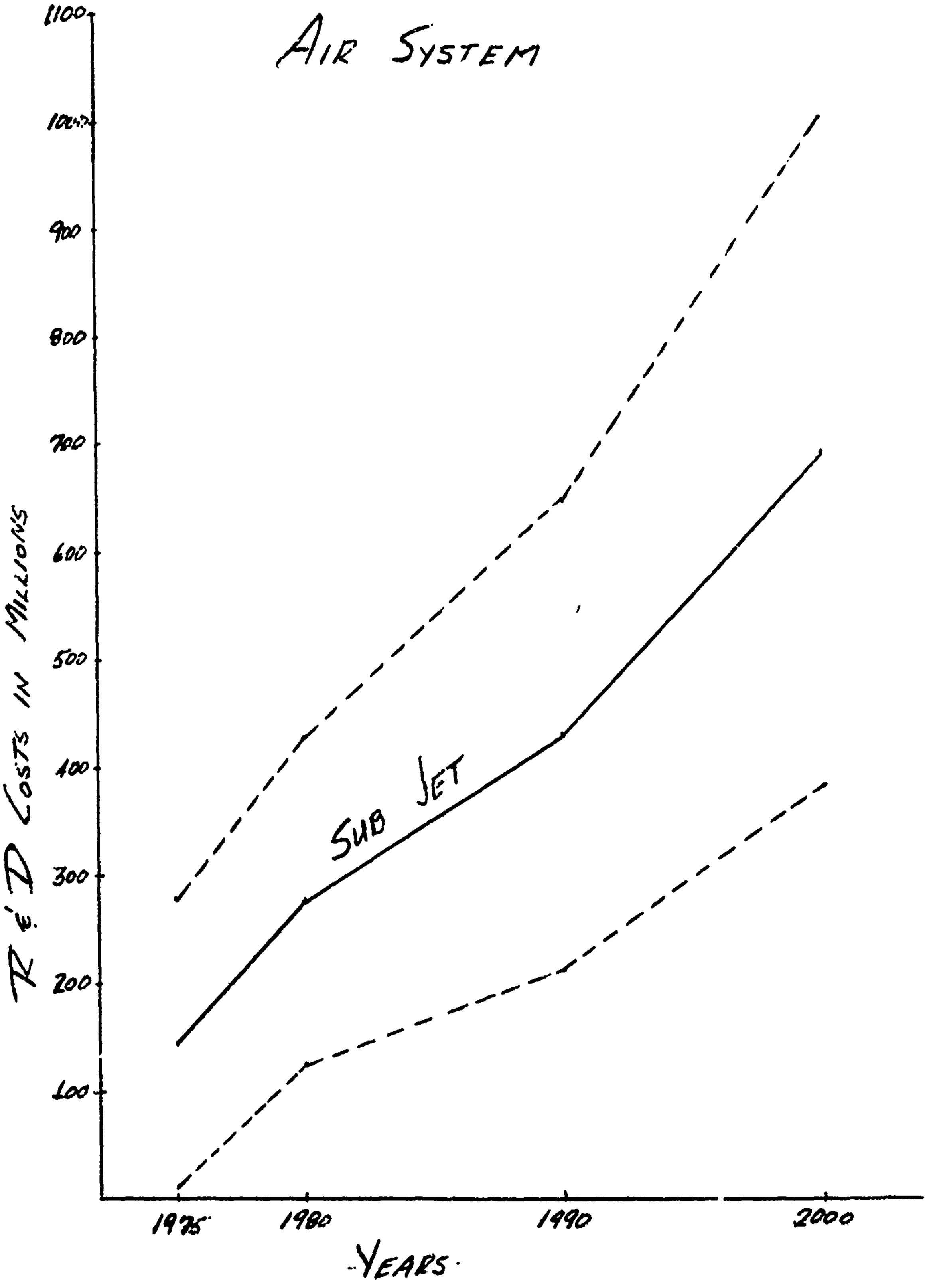
AIR SYSTEMS

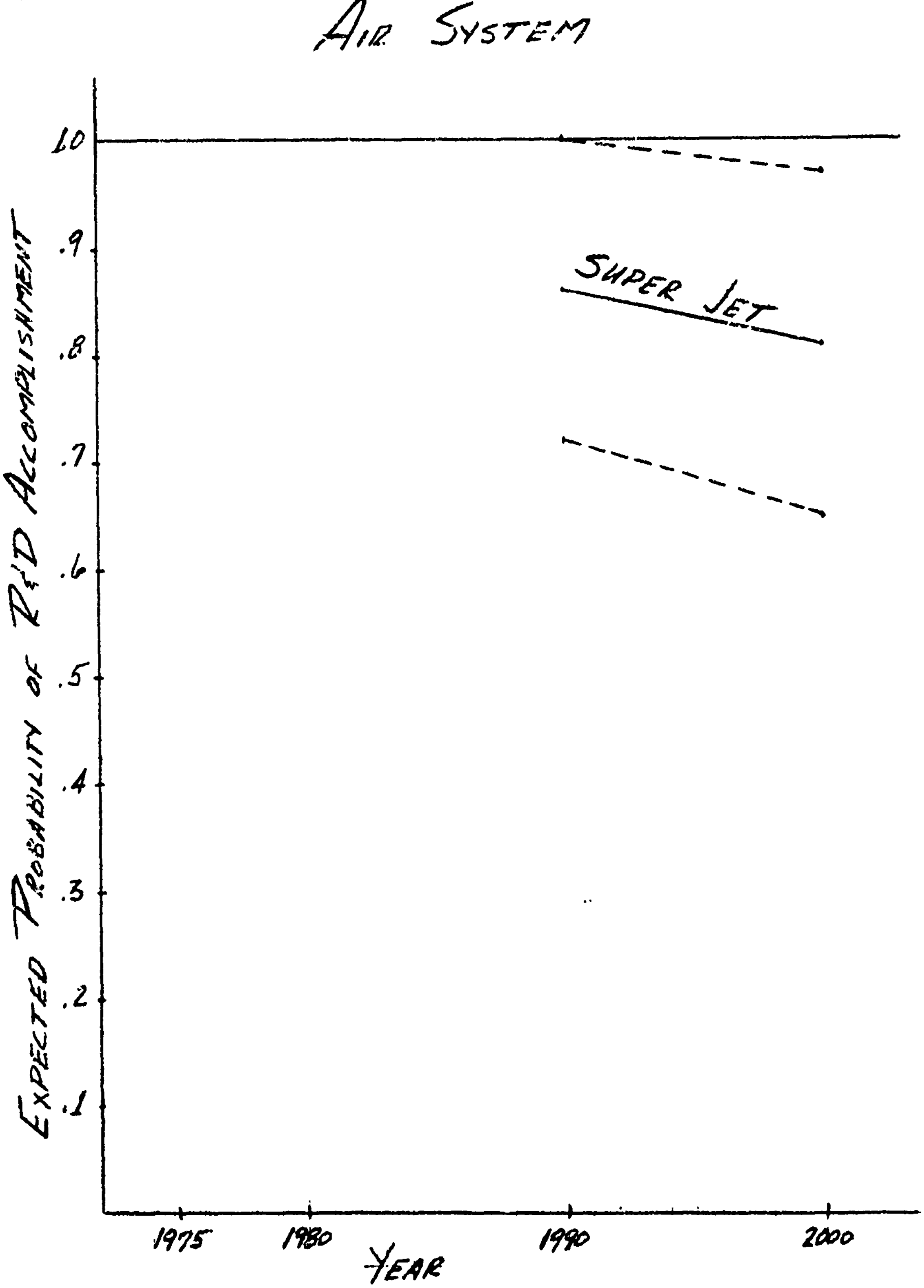



AIR SYSTEM
VTOL
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
1975
1980
1990
2000
YEAR

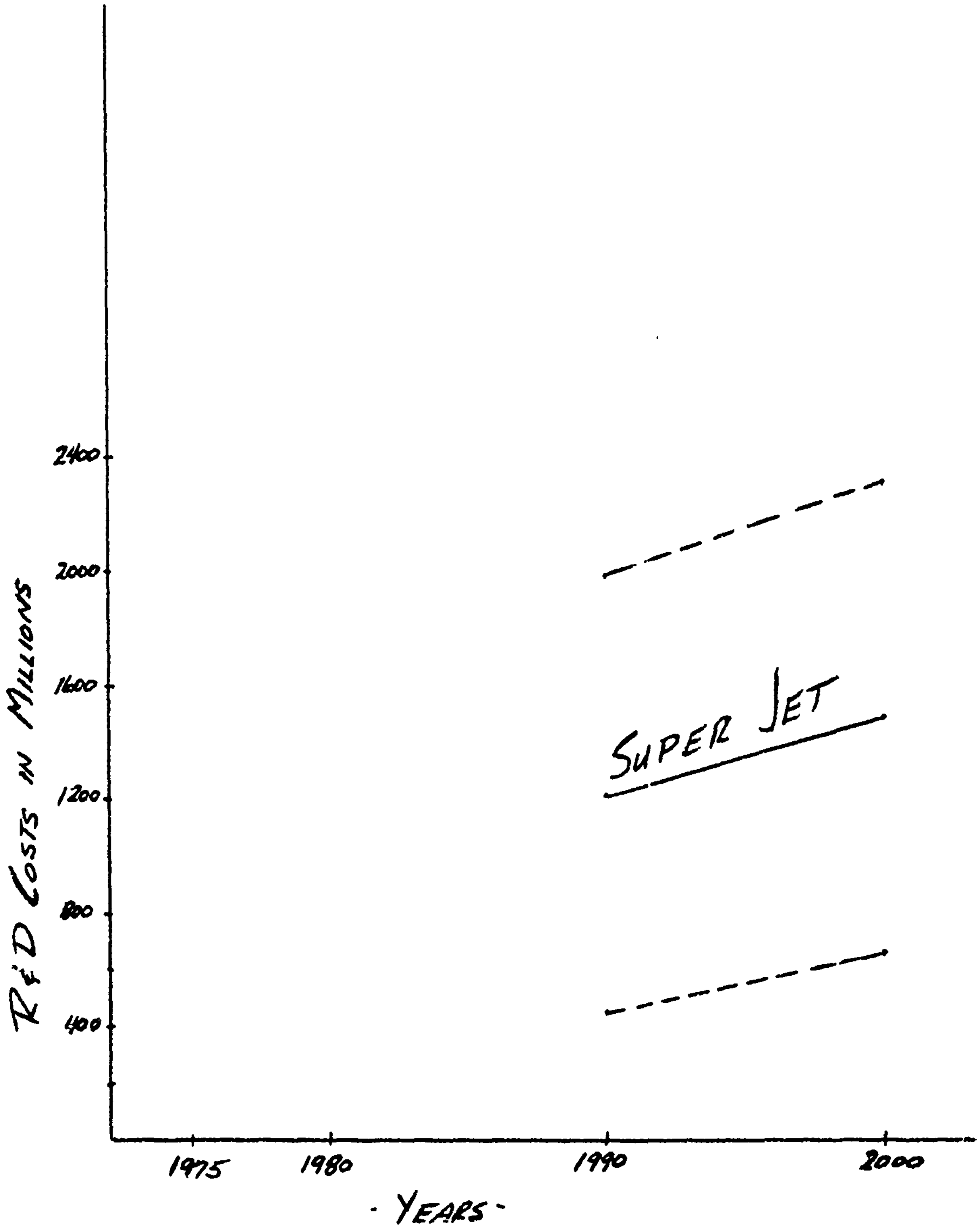

AIR SYSTEM
R&D COSTS IN MILLIONS
1400
1200
1000
800
600
400
200
VTOL
1975
1980
1990
2000
YEARS


AIR SYSTEM
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
SUB JET
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1975
1980
1990
2000
YEAR


AIR SYSTEM
R&D COSTS IN MILLIONS
1100
1000
900
800
700
600
500
400
300
200
100
SUB JET
1975
1980
1990
2000
YEARS


AIR SYSTEM
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
SUPER JET
1975
1980
1990
2000
YEAR

AIR SYSTEM


2400
2000
1600
1200
800
400
R&D COSTS IN MILLIONS
SUPER JET
1975
1980
1990
2000
· YEARS ·

Response Graphs

for

Transportation System

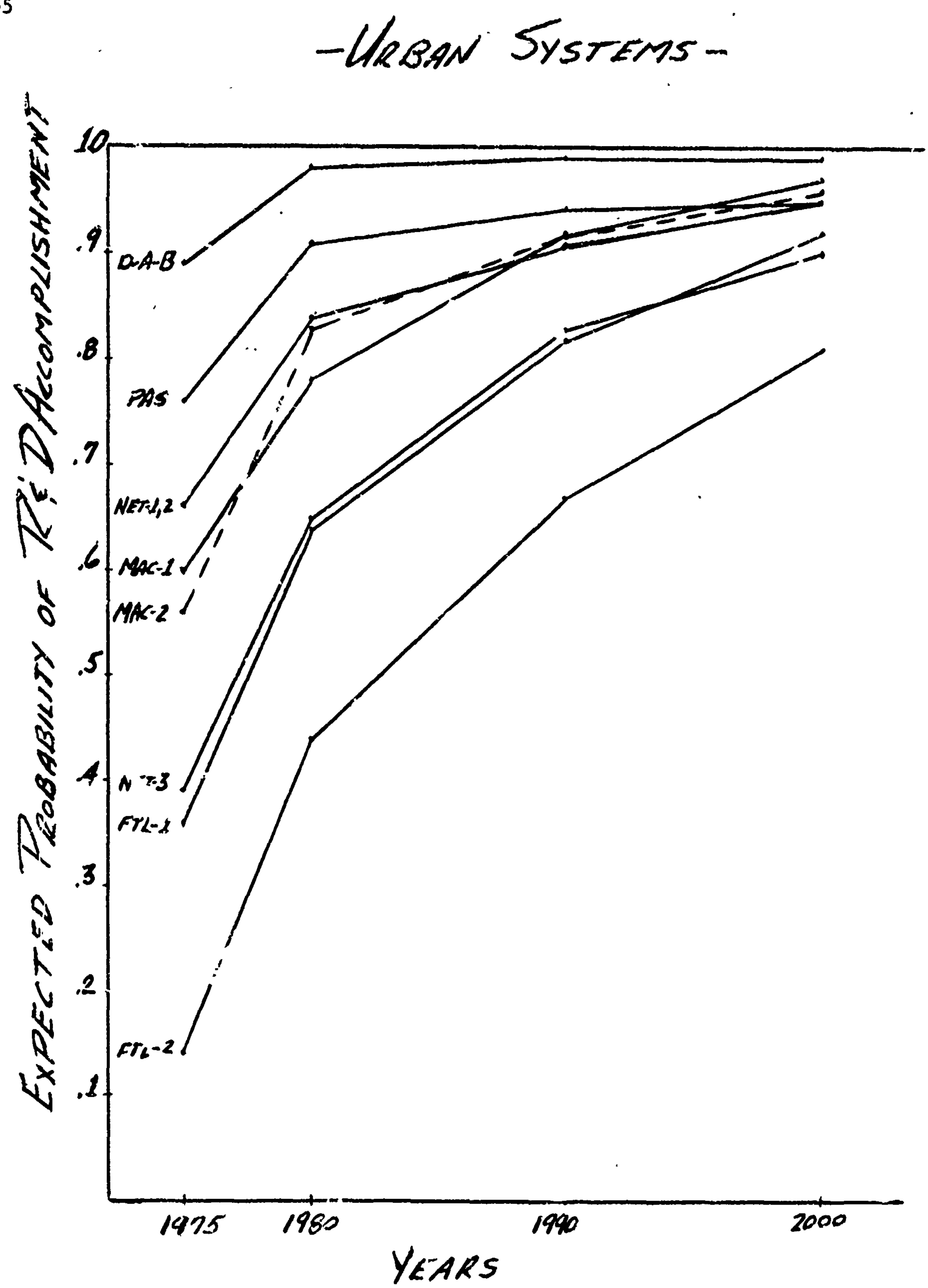
of

Delphi Exercise

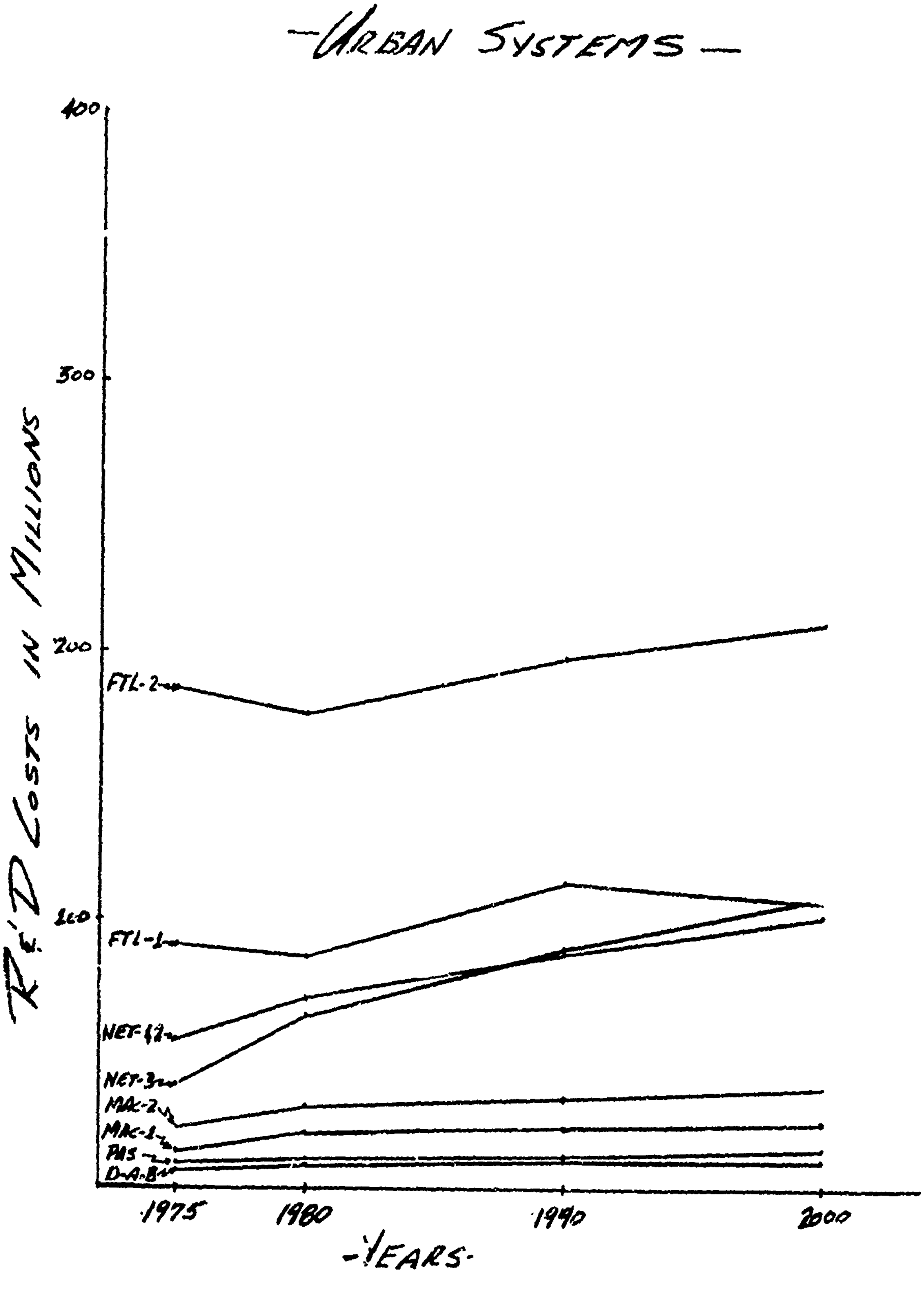
2nd Cycle

(February 1970)

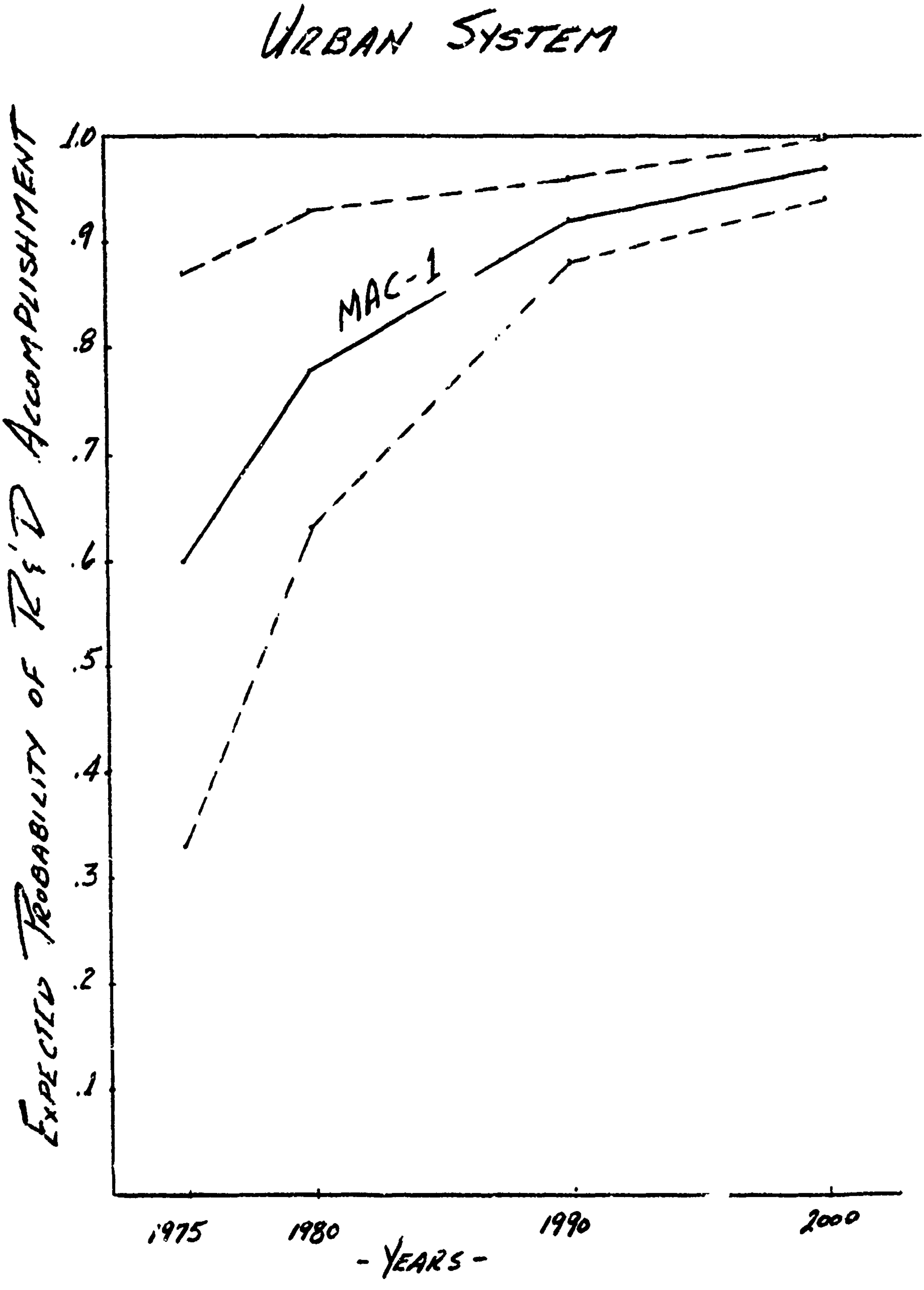
Office of Systems Requirements,
Plans and Information



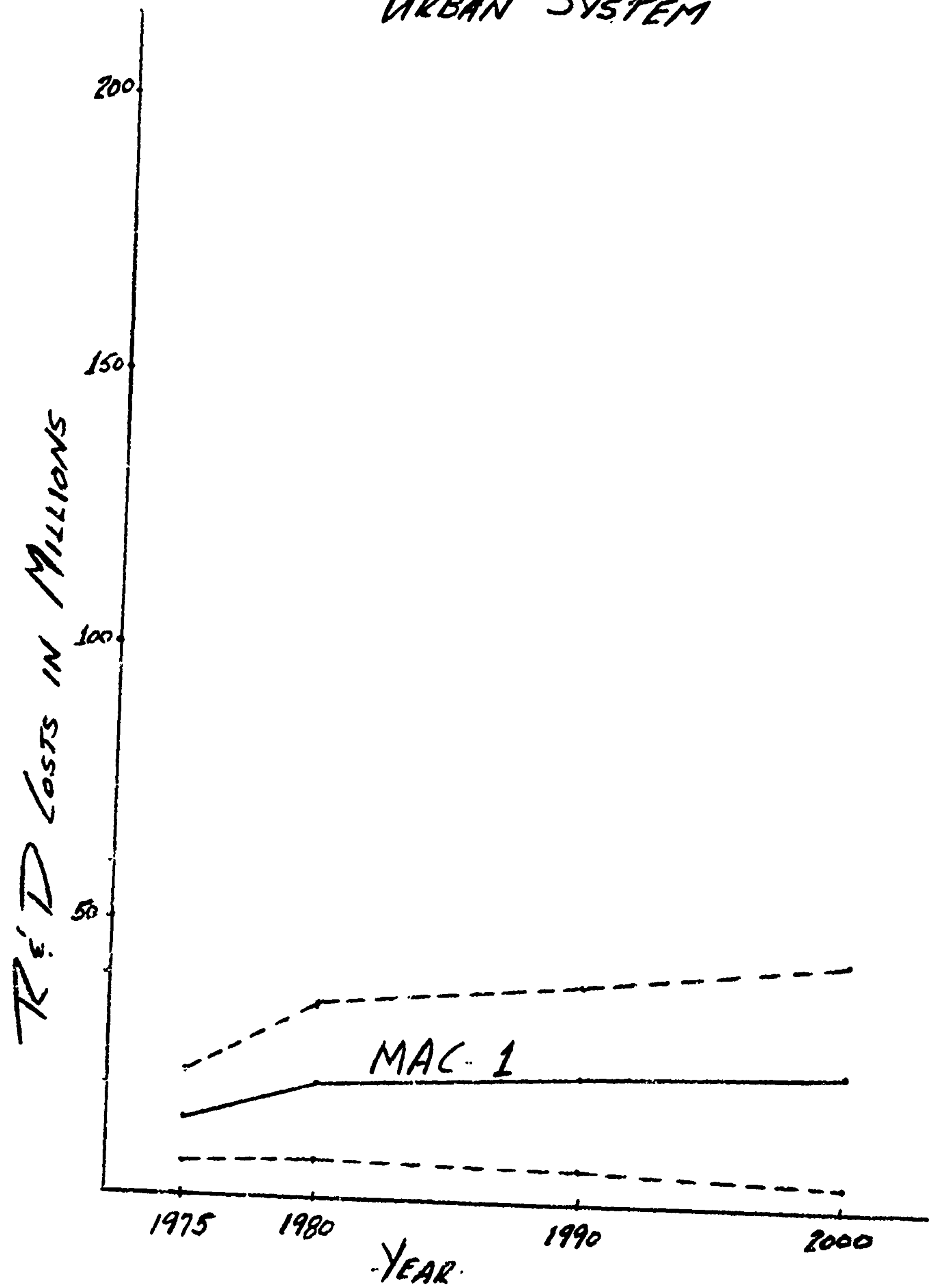
-URBAN SYSTEMS-
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
D-A-B
PAS
NET-1,2
MAC-1
MAC-2
N -T-3
FTL-1
FTL-2
1975
1980
1990
2000
YEARS



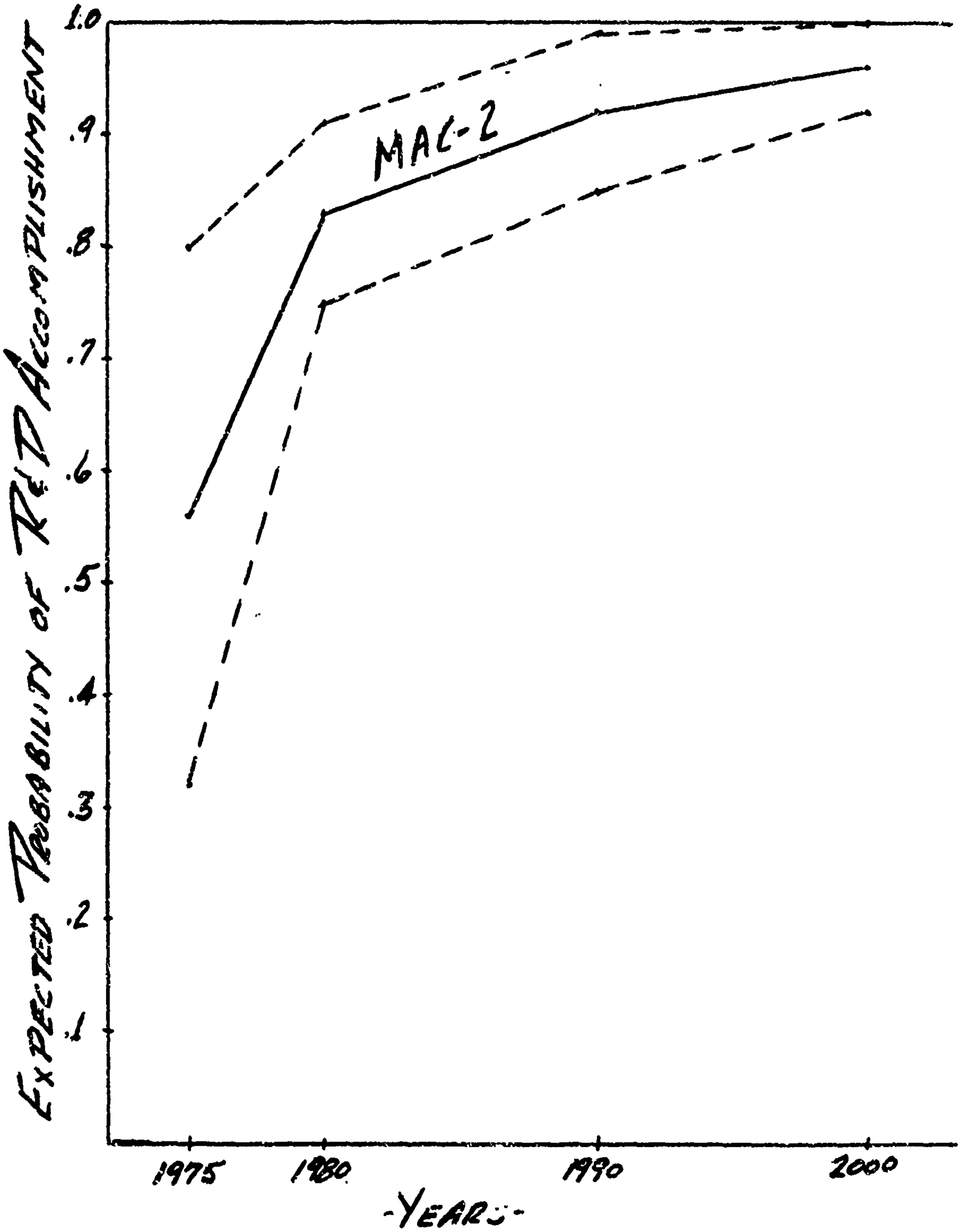
-URBAN SYSTEMS-
400
300
200
100
R&D COSTS IN MILLIONS
FTL-2
FTL-1
NET-1,2
NET-3
MAC-2
MAC-1
PHS
D-A-B
1975
1980
1990
2000
-YEARS-

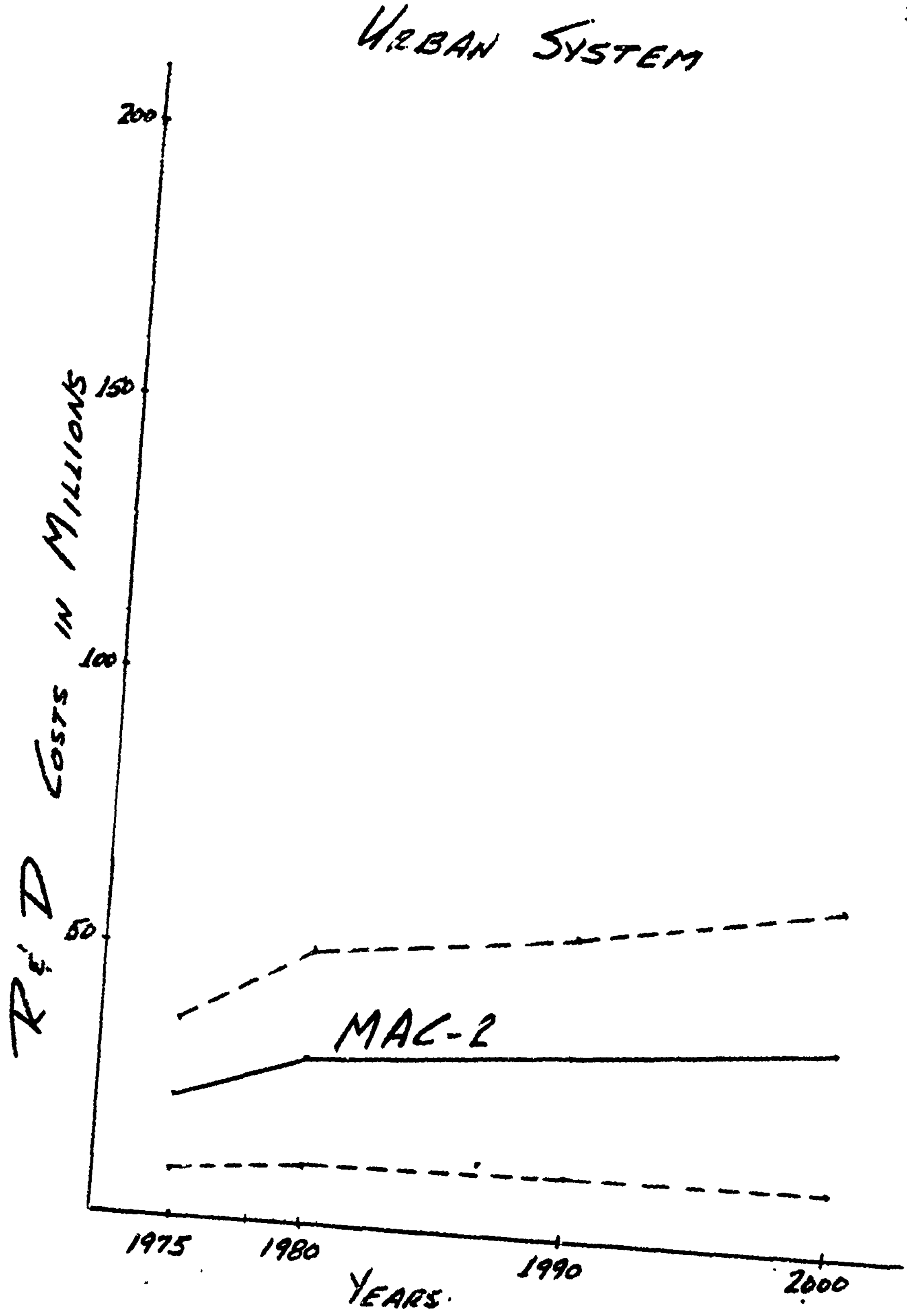

URBAN SYSTEM
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
MAC-1
1975
1980
1990
2000
- YEARS -

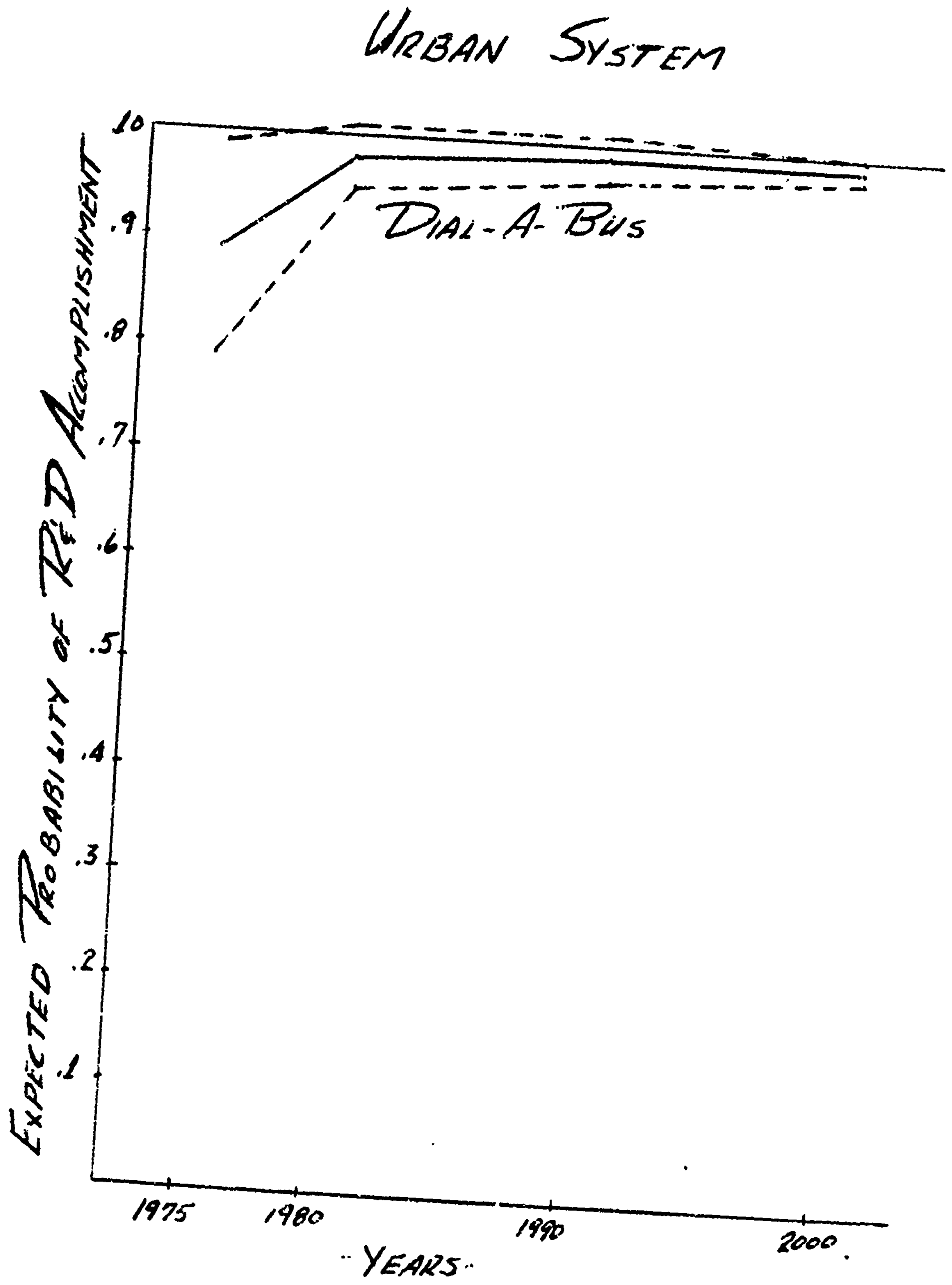
URBAN SYSTEM

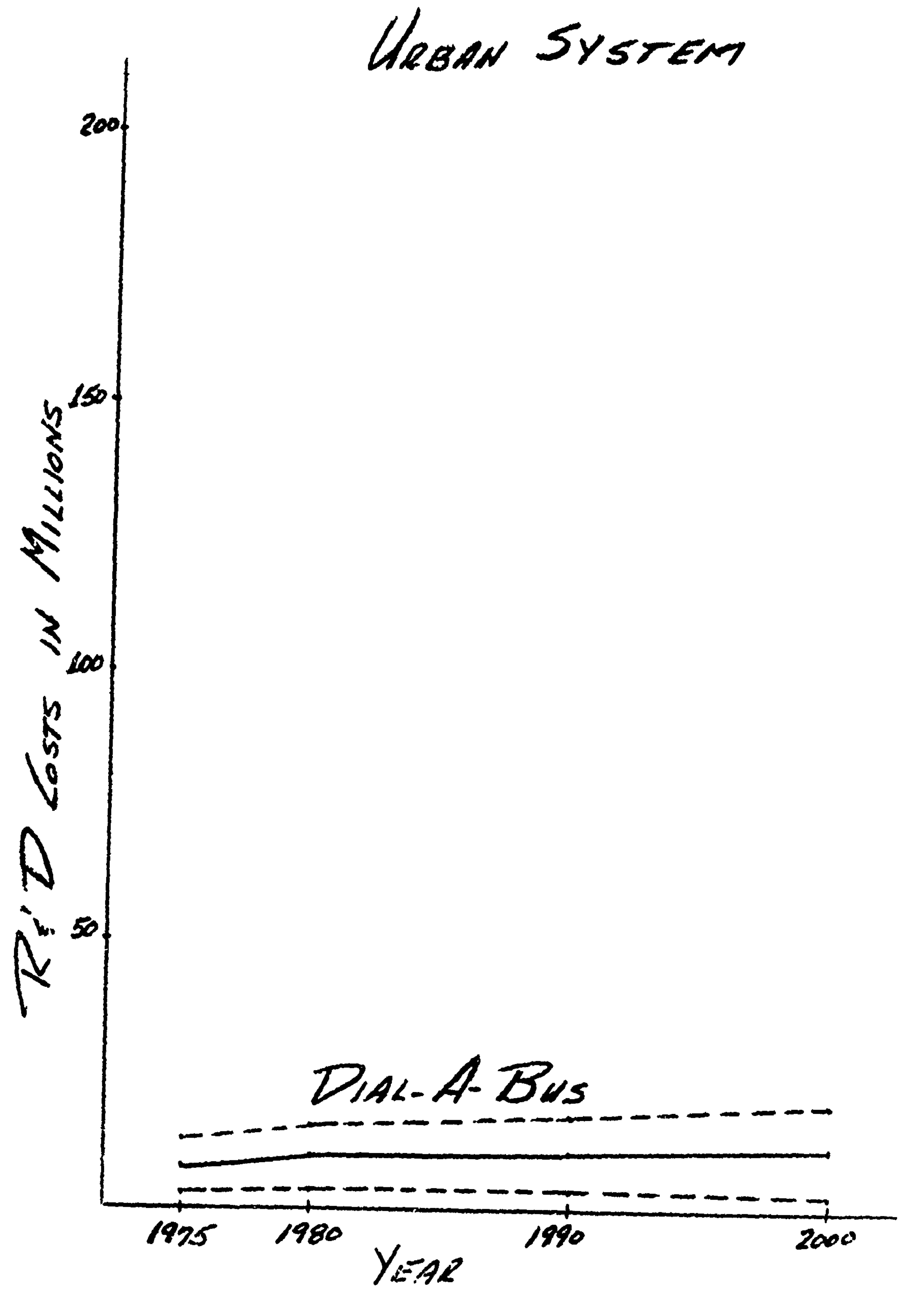


URBAN SYSTEM

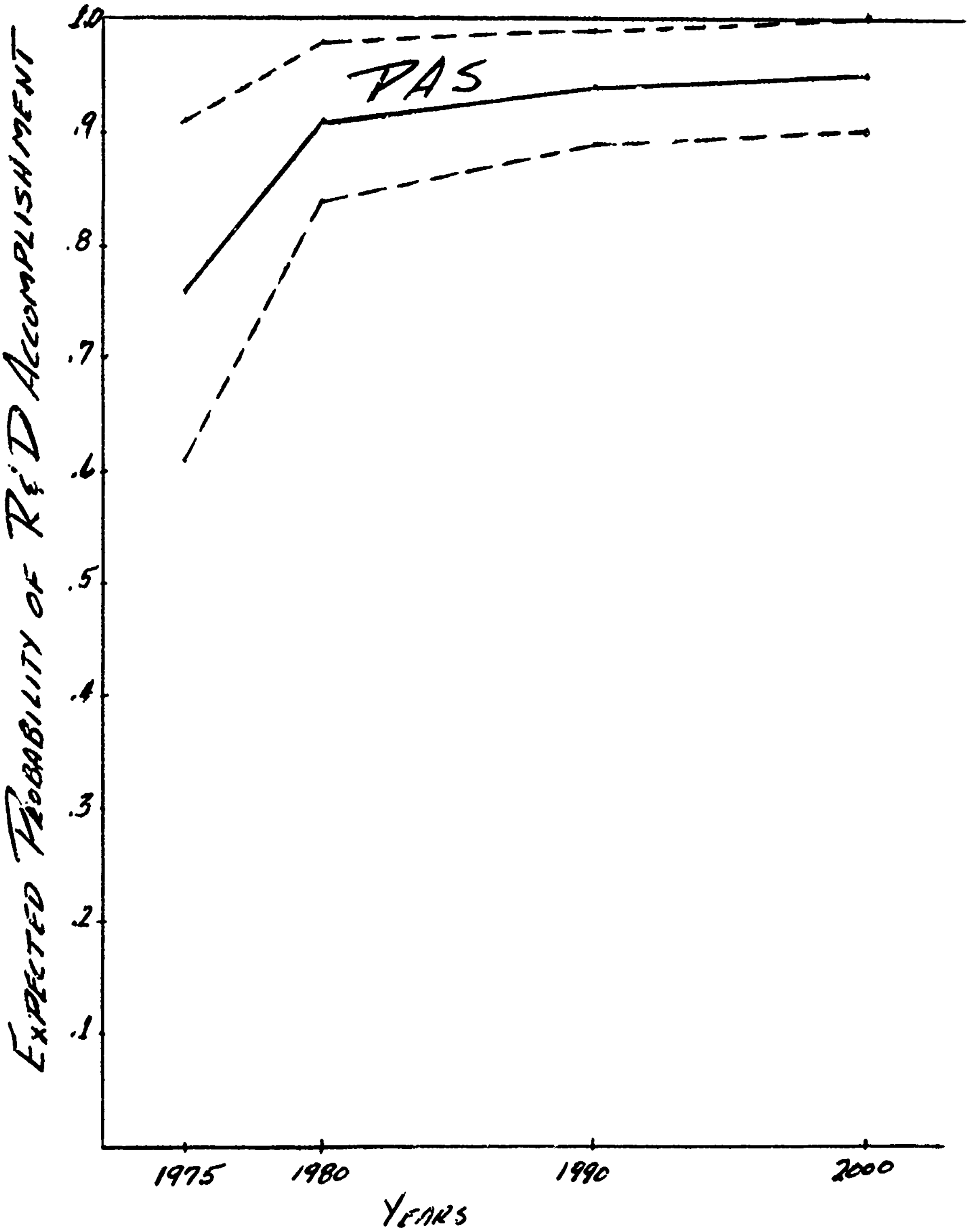


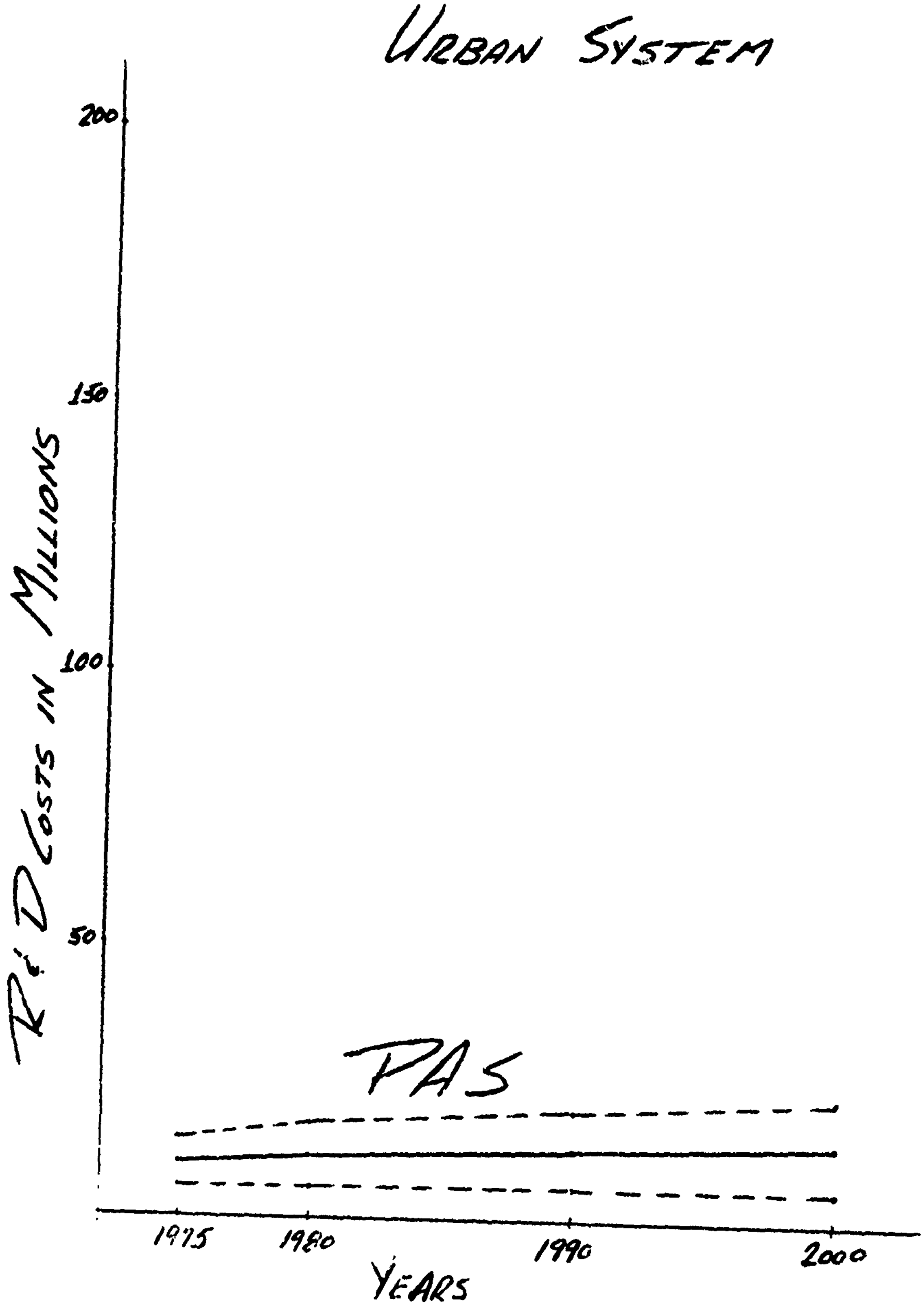

URBAN SYSTEM
R&D COSTS IN MILLIONS
200
150
100
50
MAC-2
1975
1980
1990
2000
YEARS

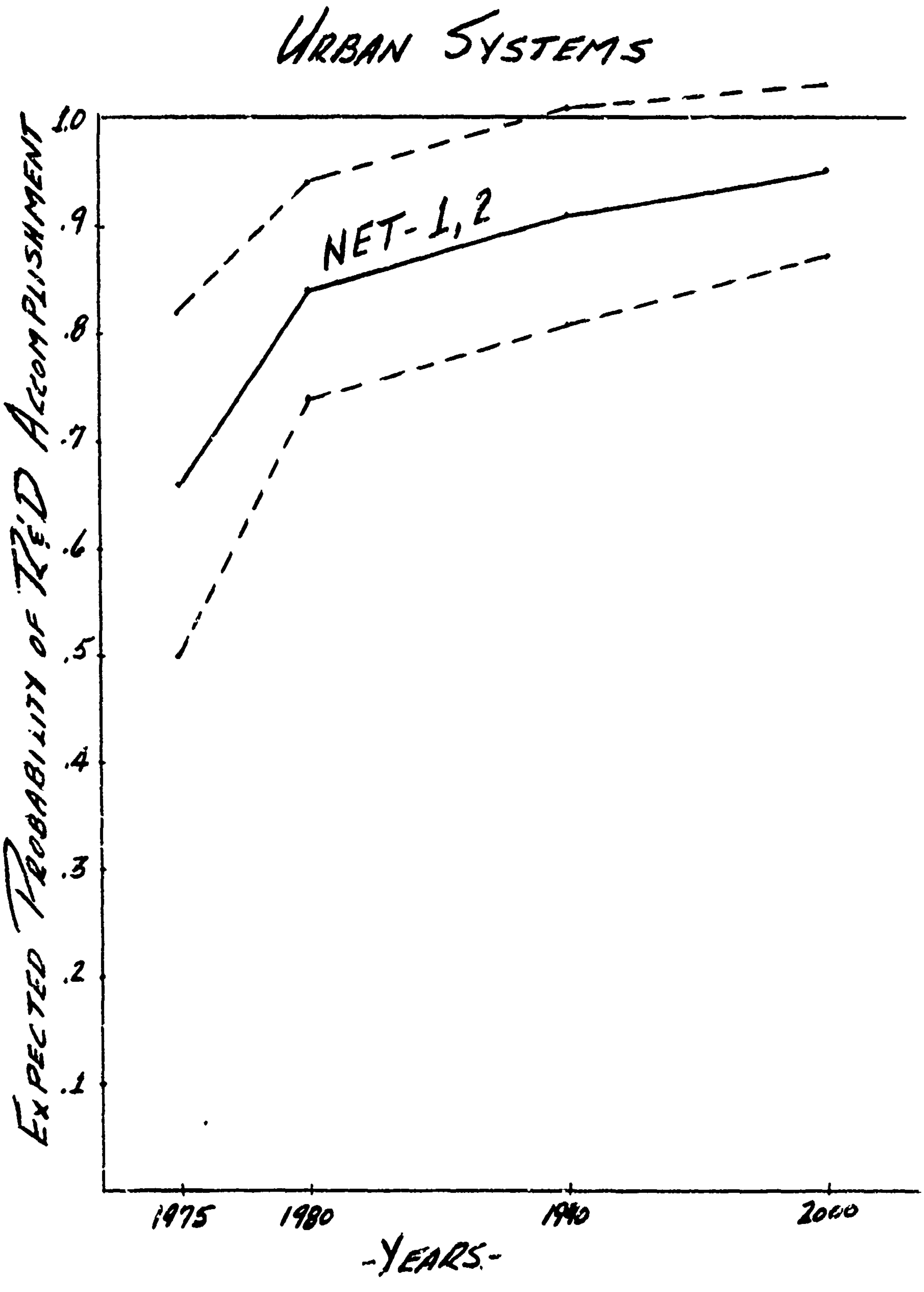

URBAN SYSTEM
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
DIAL-A-BUS
1975
1980
1990
2000
YEARS

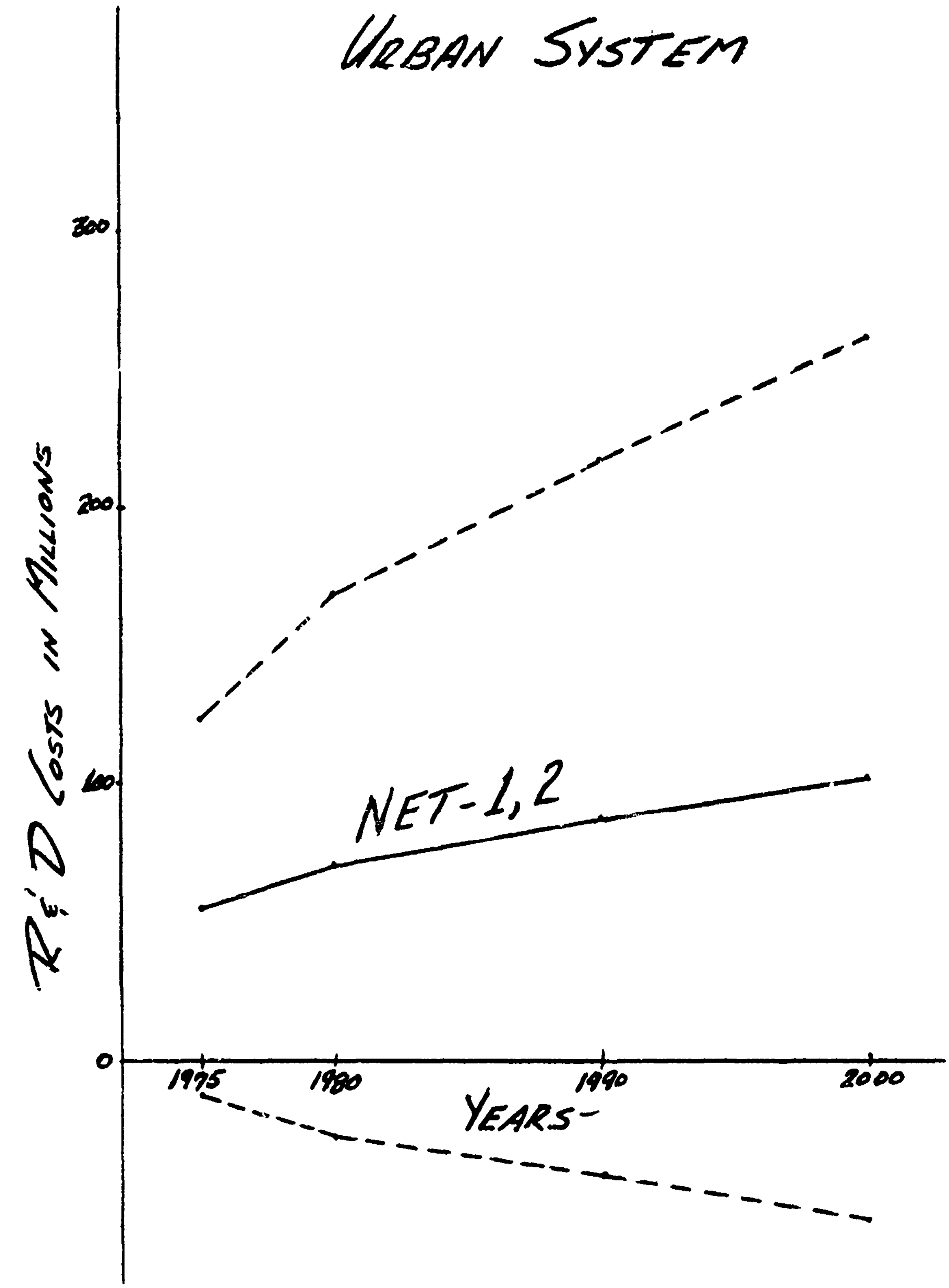

URBAN SYSTEM
200
150
100
50
R&D COSTS IN MILLIONS
DIAL-A-BUS
1975
1980
1990
2000
YEAR

URBAN SYSTEM



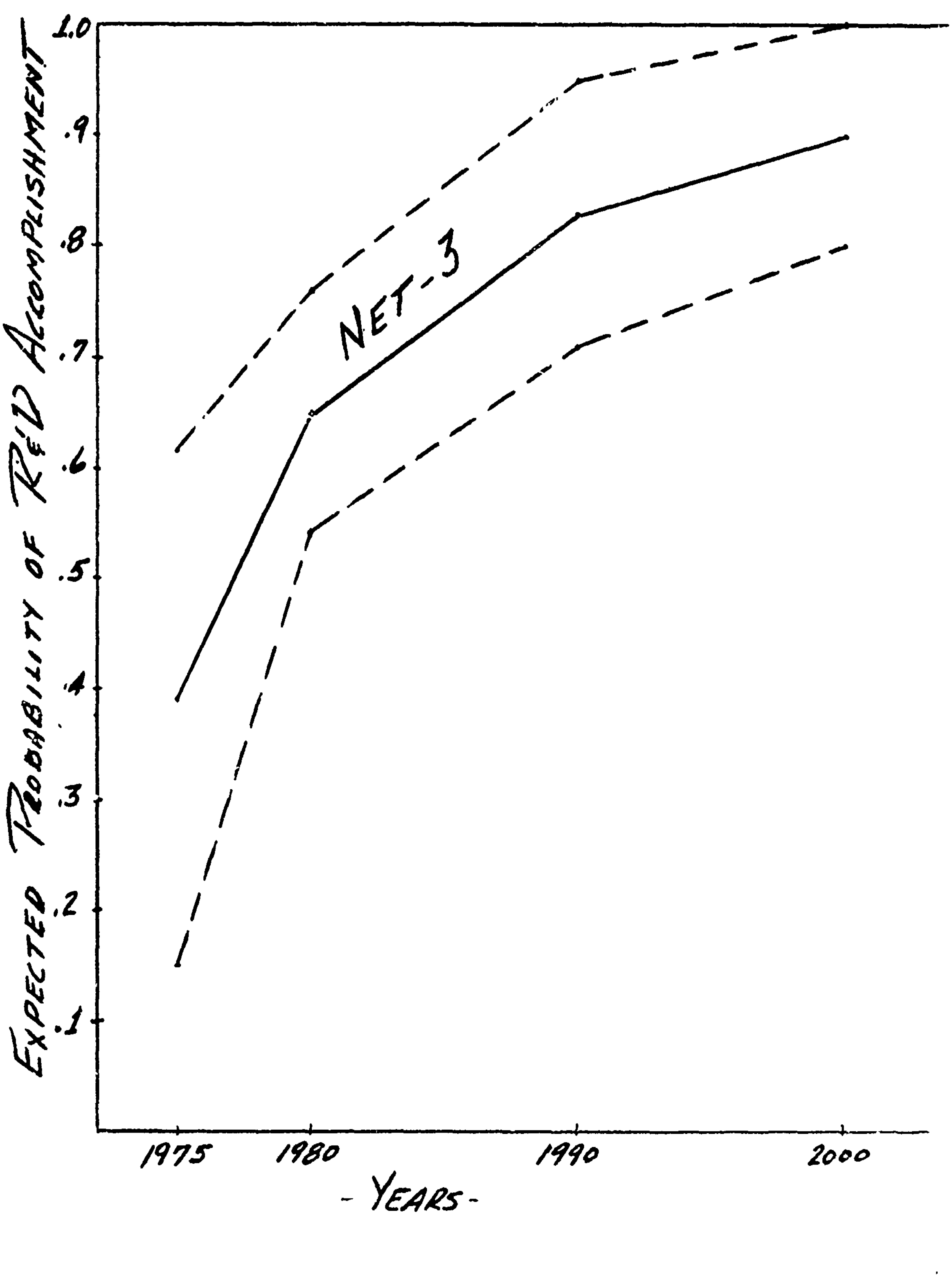

URBAN SYSTEM
200
150
100
50
R&D COSTS IN MILLIONS
PAS
1975
1980
1990
2000
YEARS

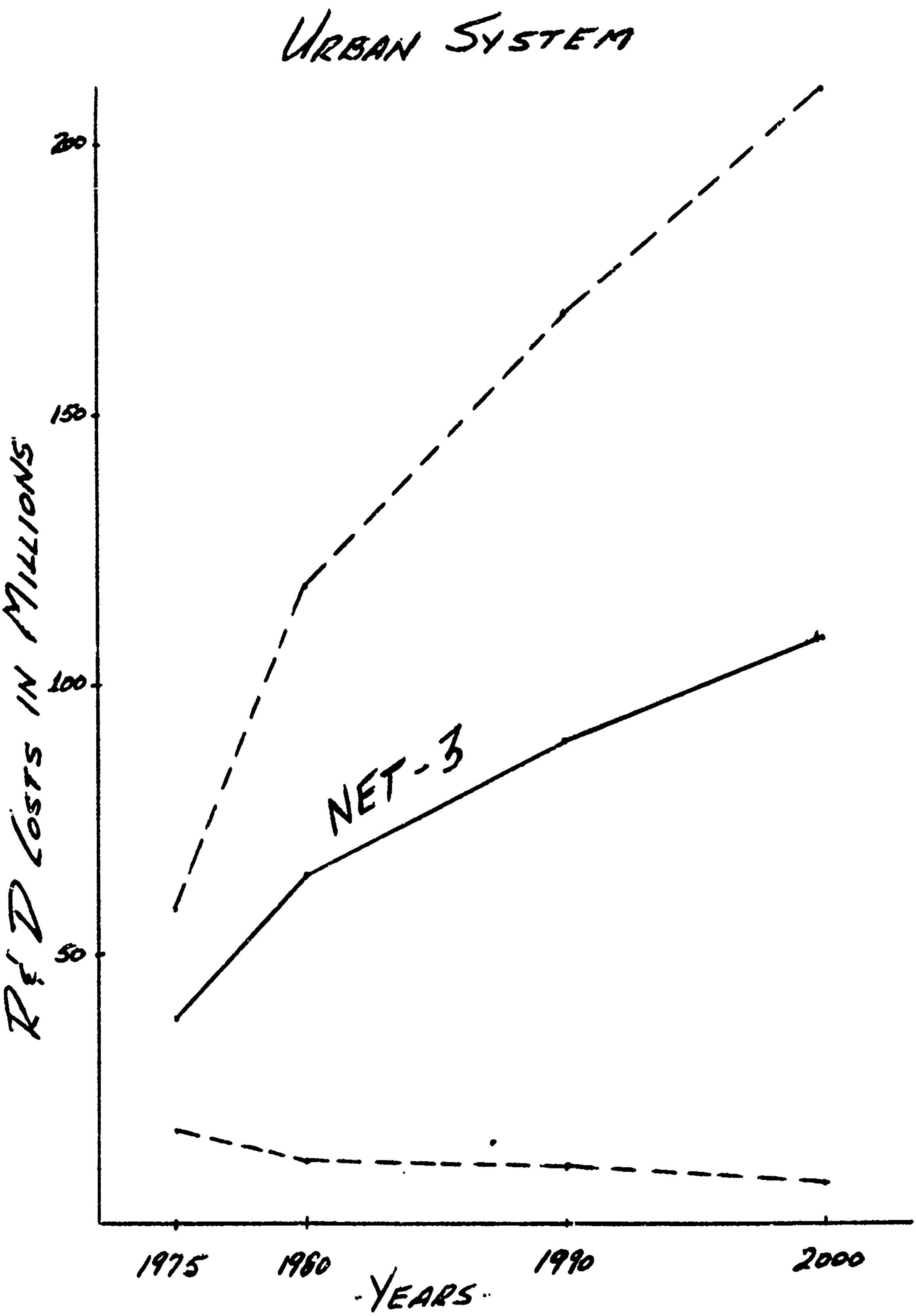

URBAN SYSTEMS
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
NET-1,2
1975
1980
1990
2000
-YEARS-

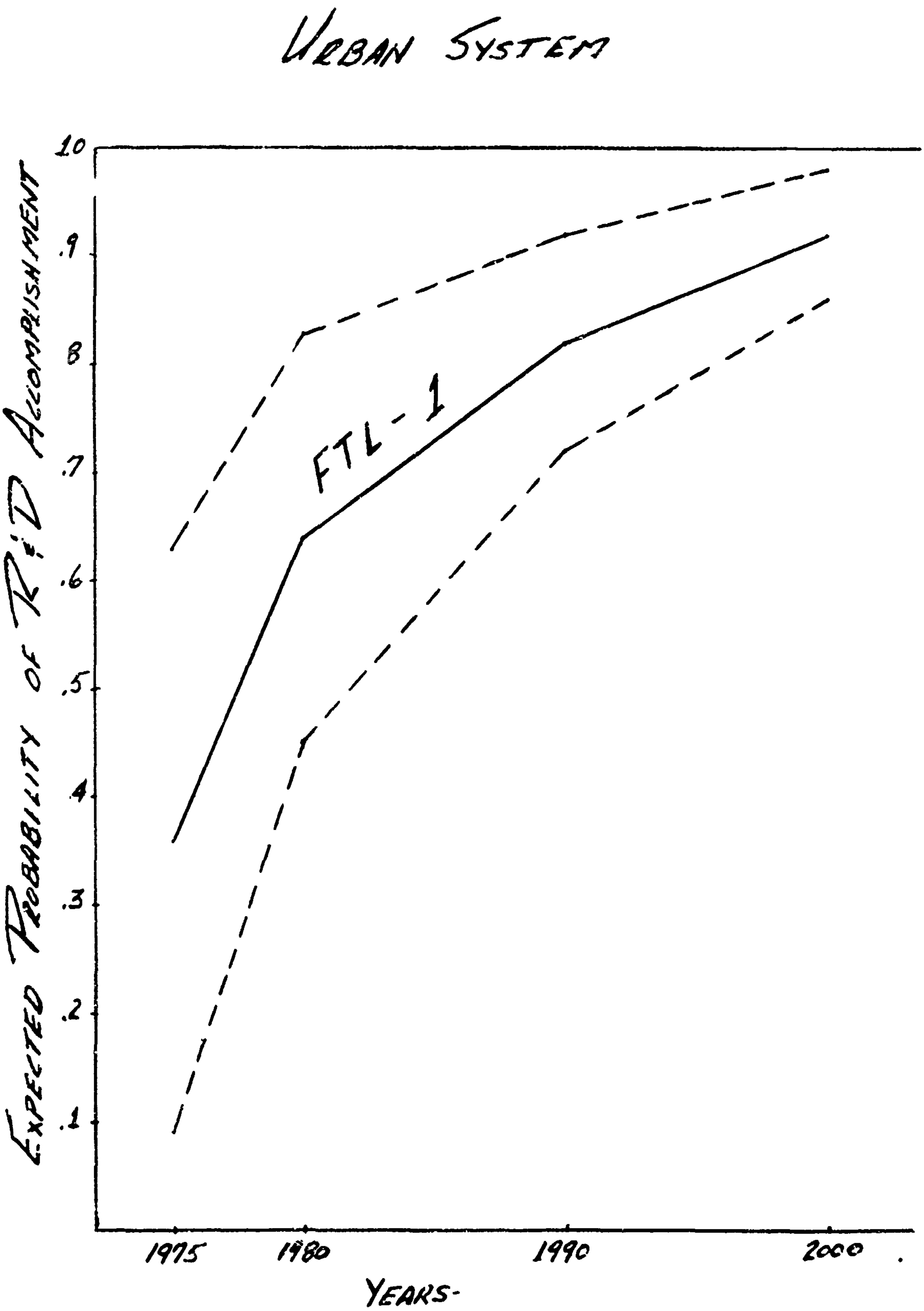


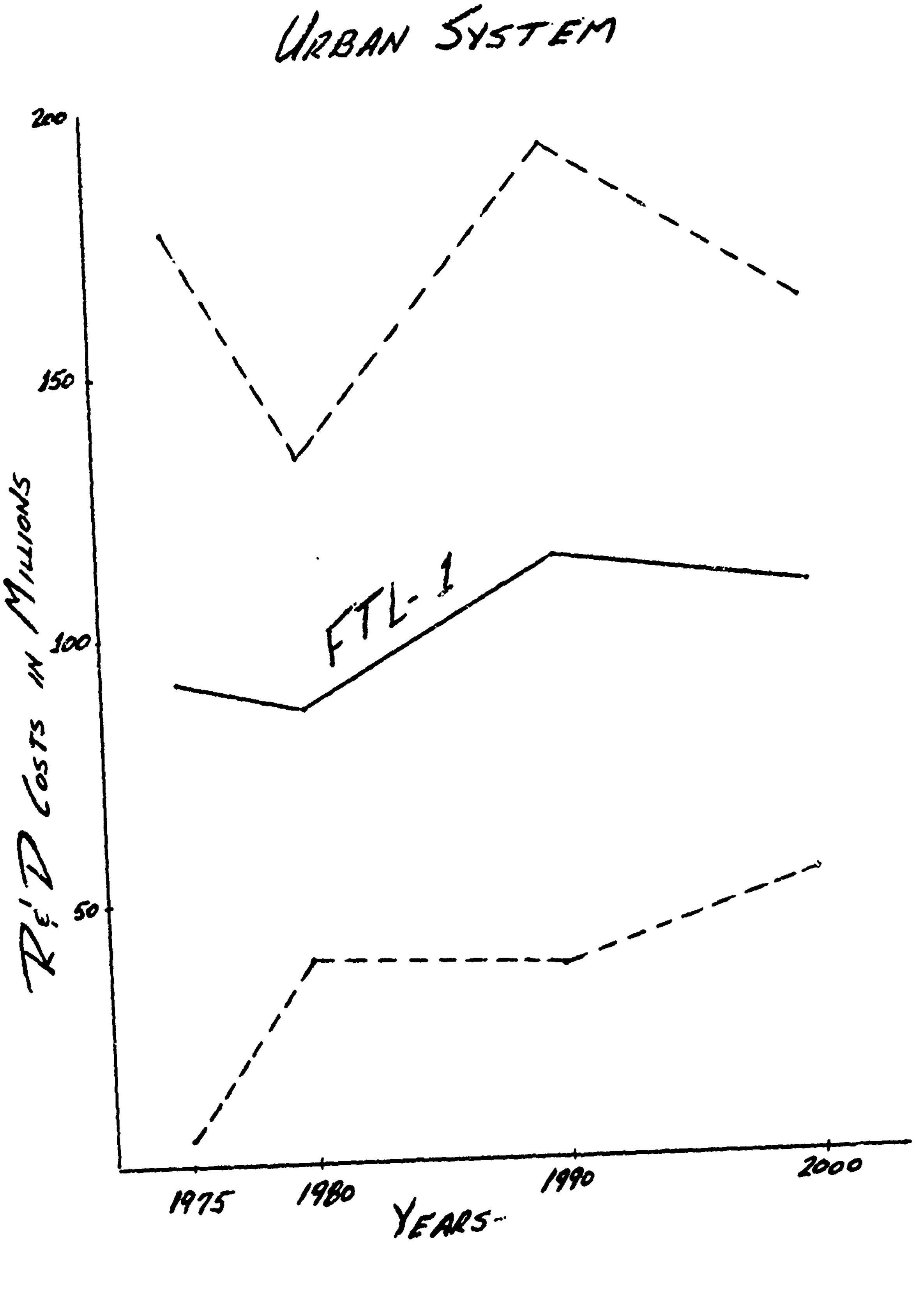
URBAN SYSTEM
R&D COSTS IN MILLIONS
300
200
100
0
NET-1,2
1975
1980
1990
2000
YEARS

URBAN SYSTEM

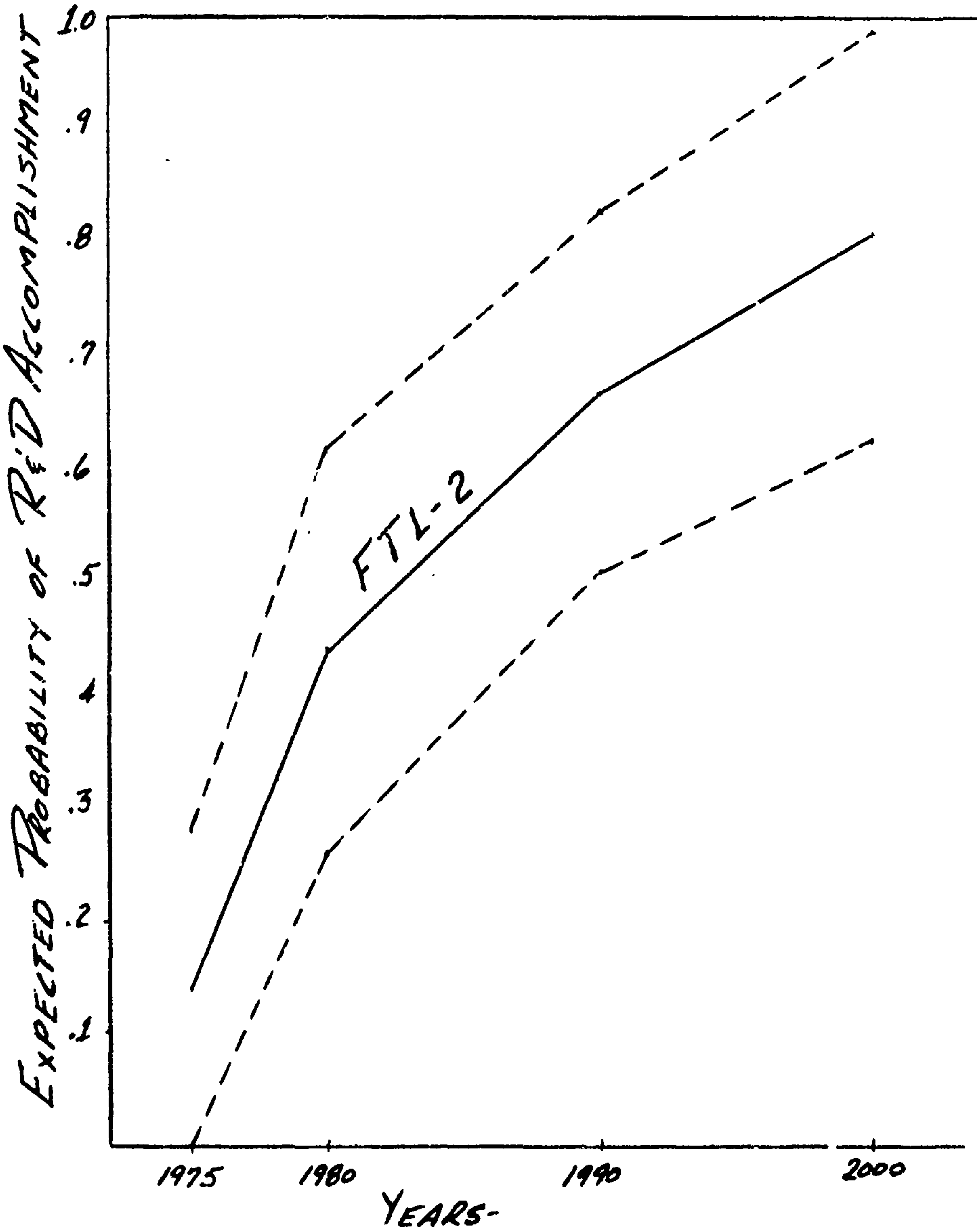


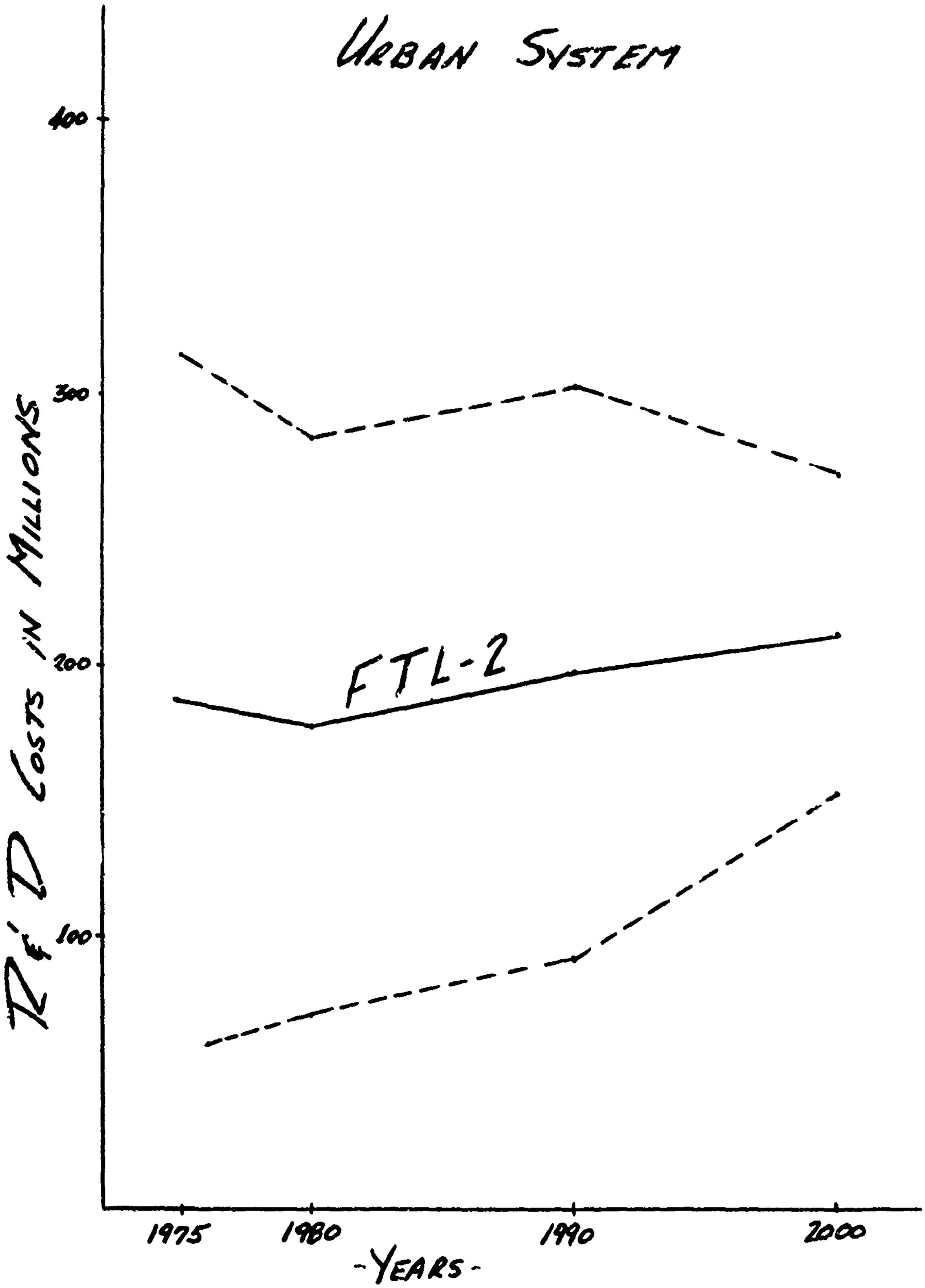

URBAN SYSTEM
200
150
100
50
R&D COSTS IN MILLIONS
NET-3
1975
1980
1990
2000
YEARS

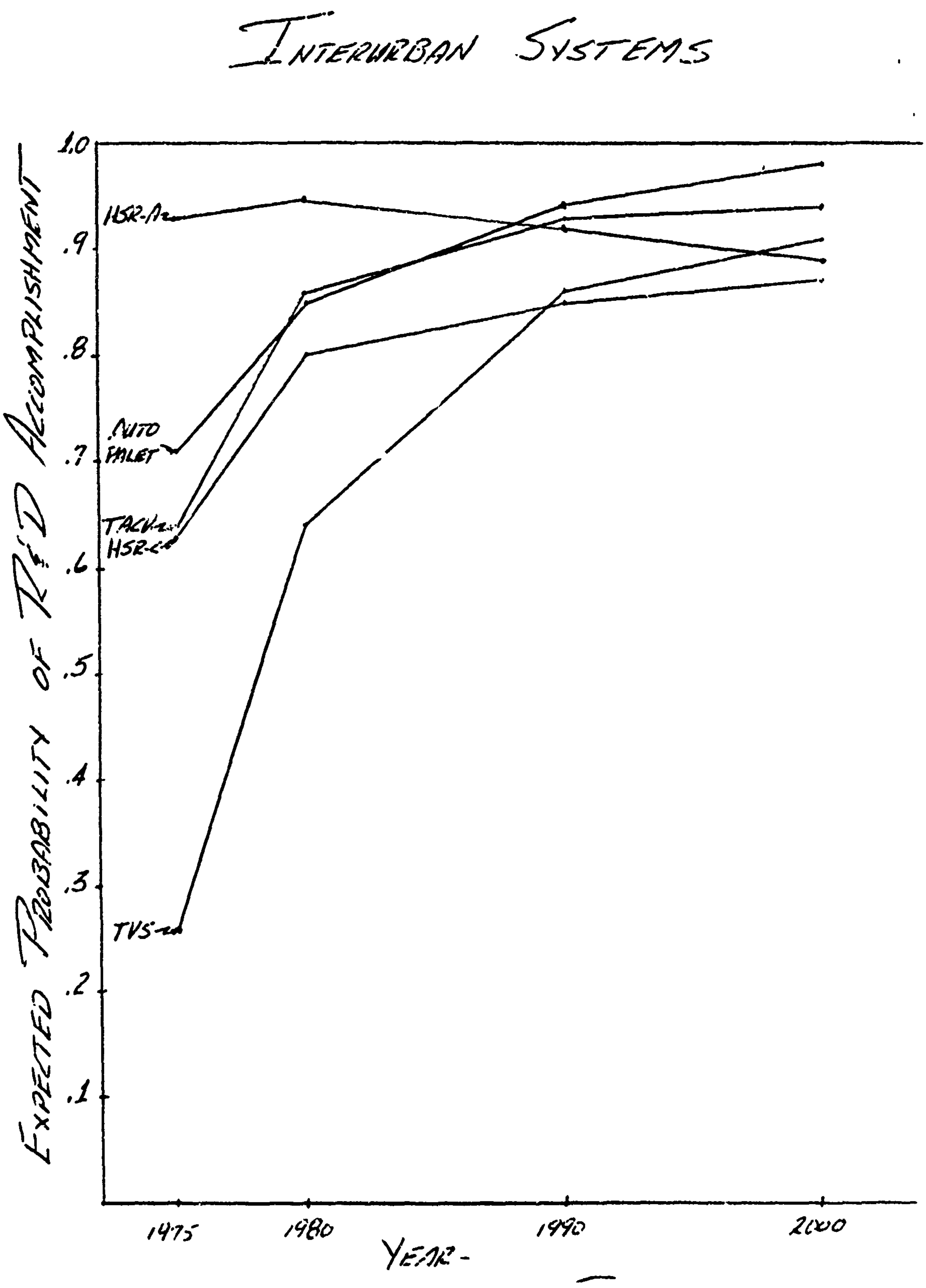

URBAN SYSTEM
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
FTL-1
1975
1980
1990
2000
YEARS

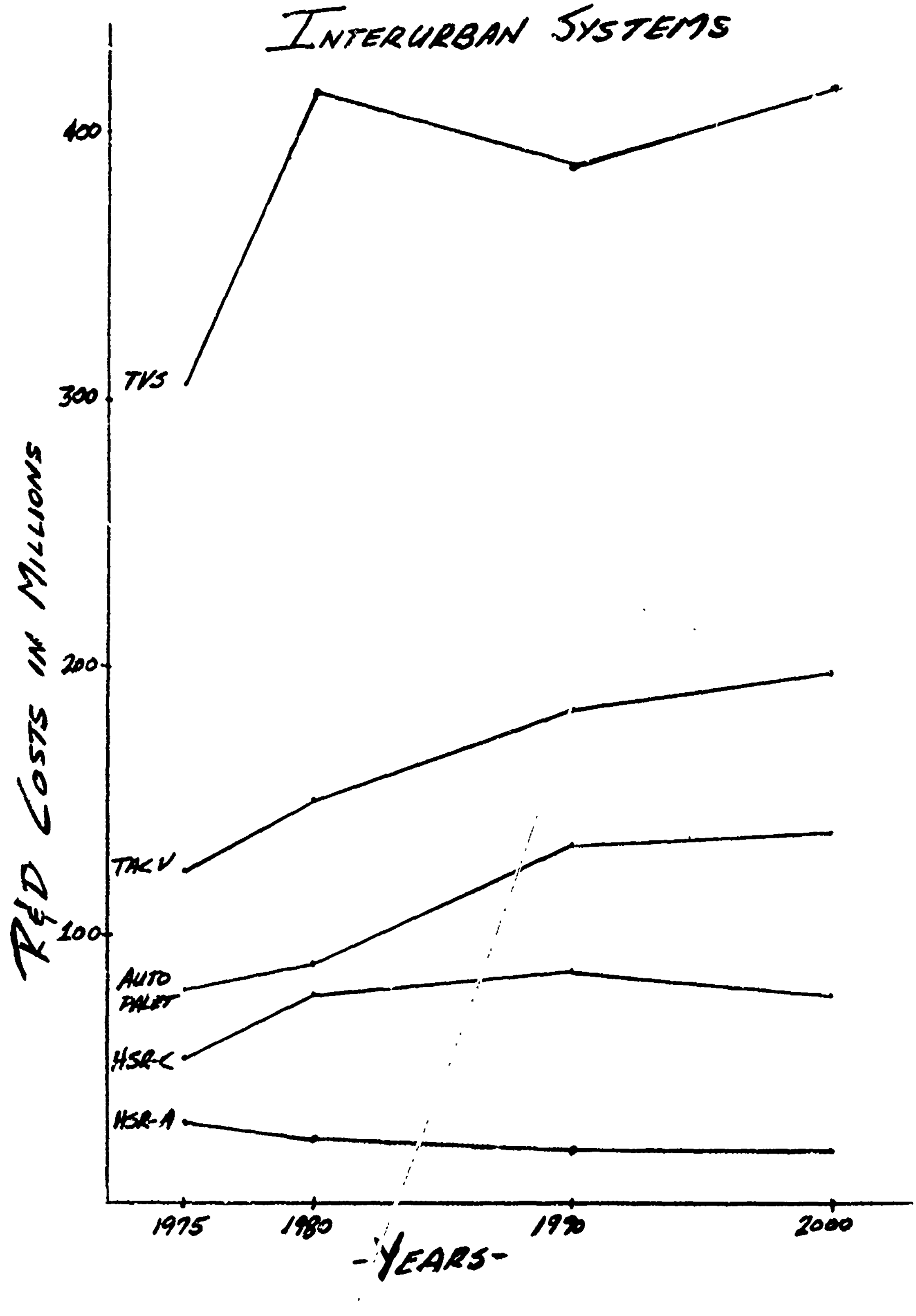

URBAN SYSTEM
200
150
100
50
R & D COSTS IN MILLIONS
FTL-1
1975
1980
1990
2000
YEARS

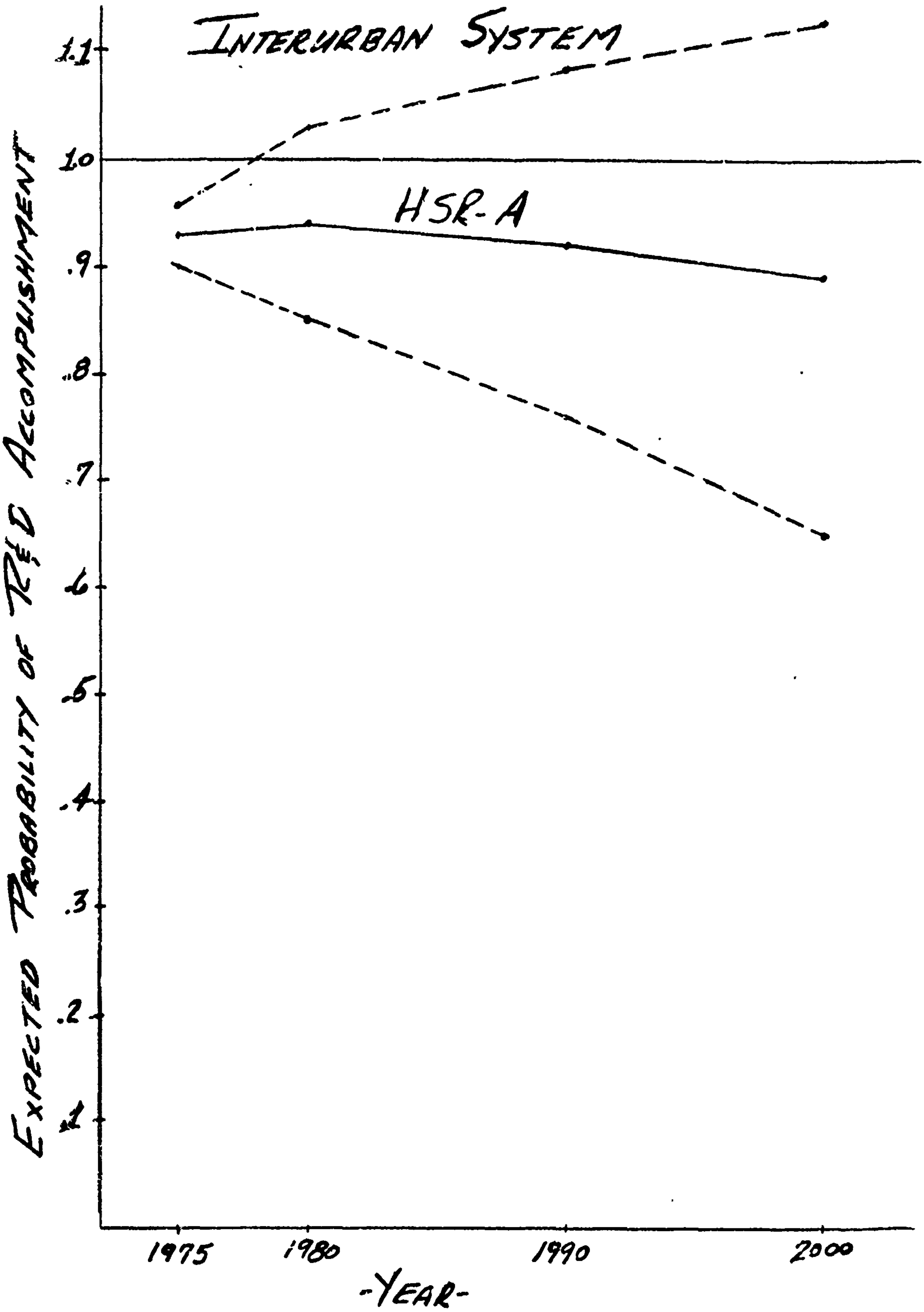
URBAN SYSTEM



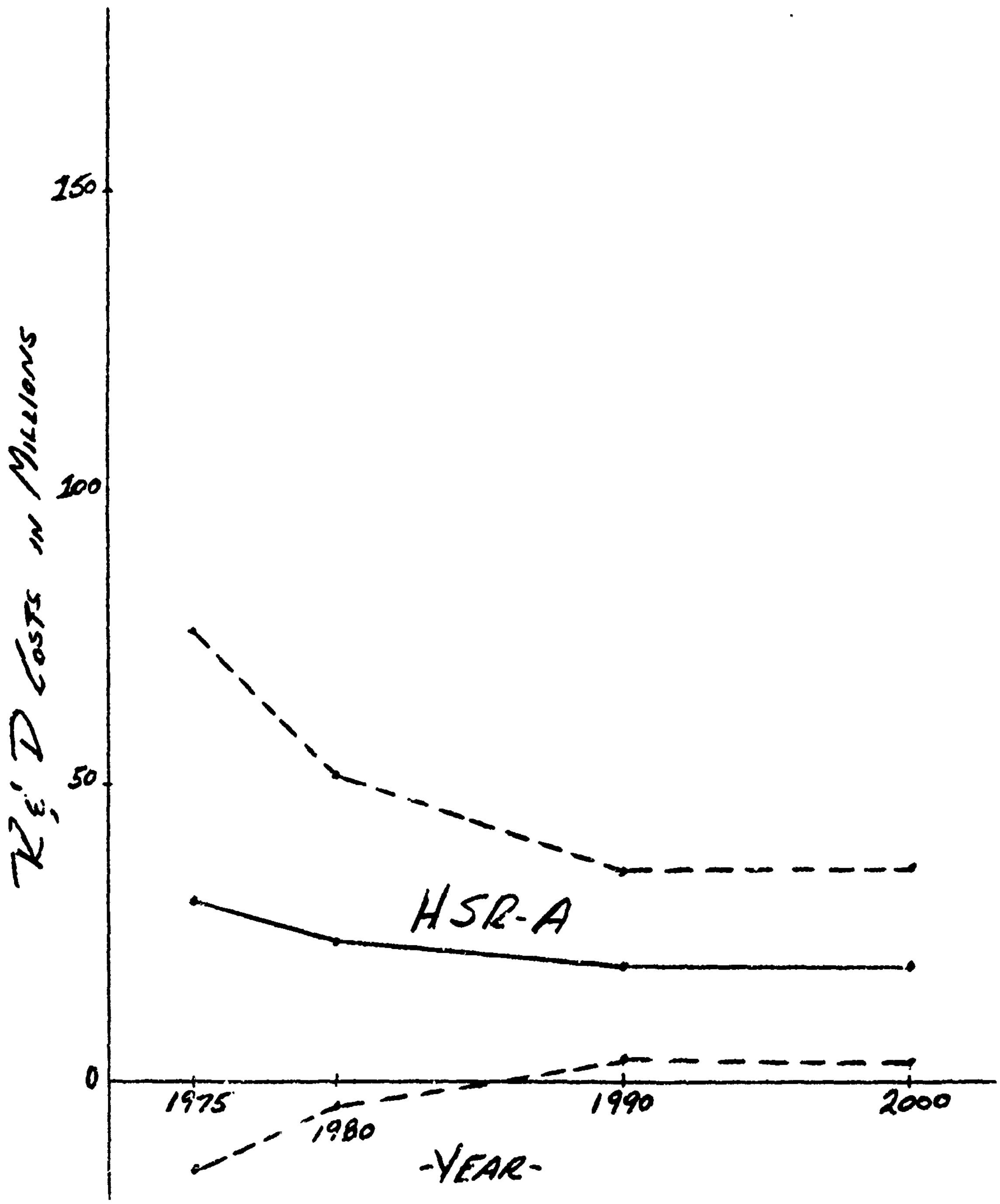

URBAN SYSTEM
R&D COSTS IN MILLIONS
400
300
200
100
FTL-2
1975
1980
1990
2000
-YEARS-

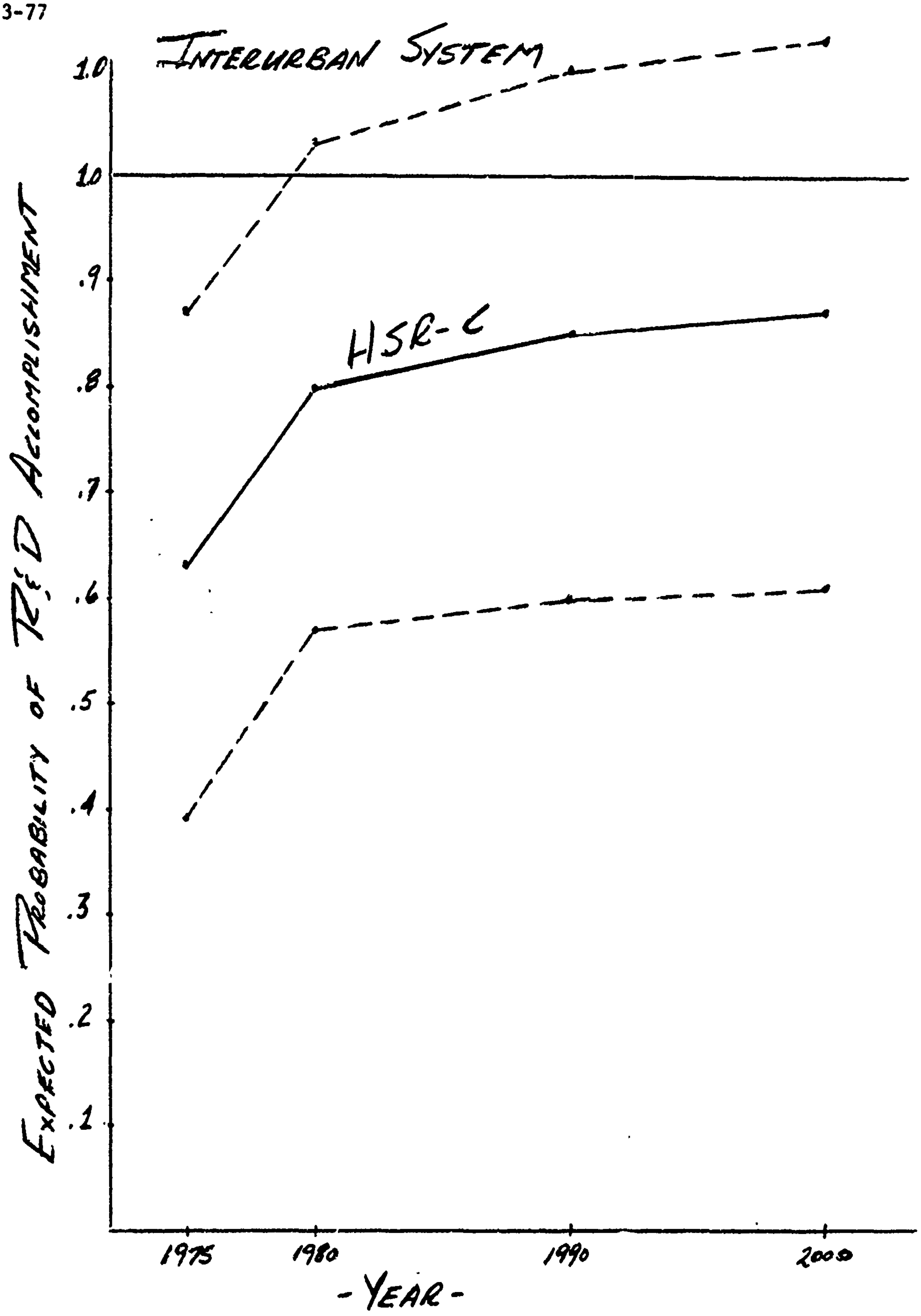

INTERURBAN SYSTEMS
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
HSR-A
AUTO PALET
TACV
HSR-C
TVS
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1975
1980
1990
2000
YEAR


INTERURBAN SYSTEMS
R&D COSTS IN MILLIONS
400
300
200
100
TVS
TACV
AUTO PALET
HSR-C
HSR-A
1975
1980
1990
2000
-YEARS-

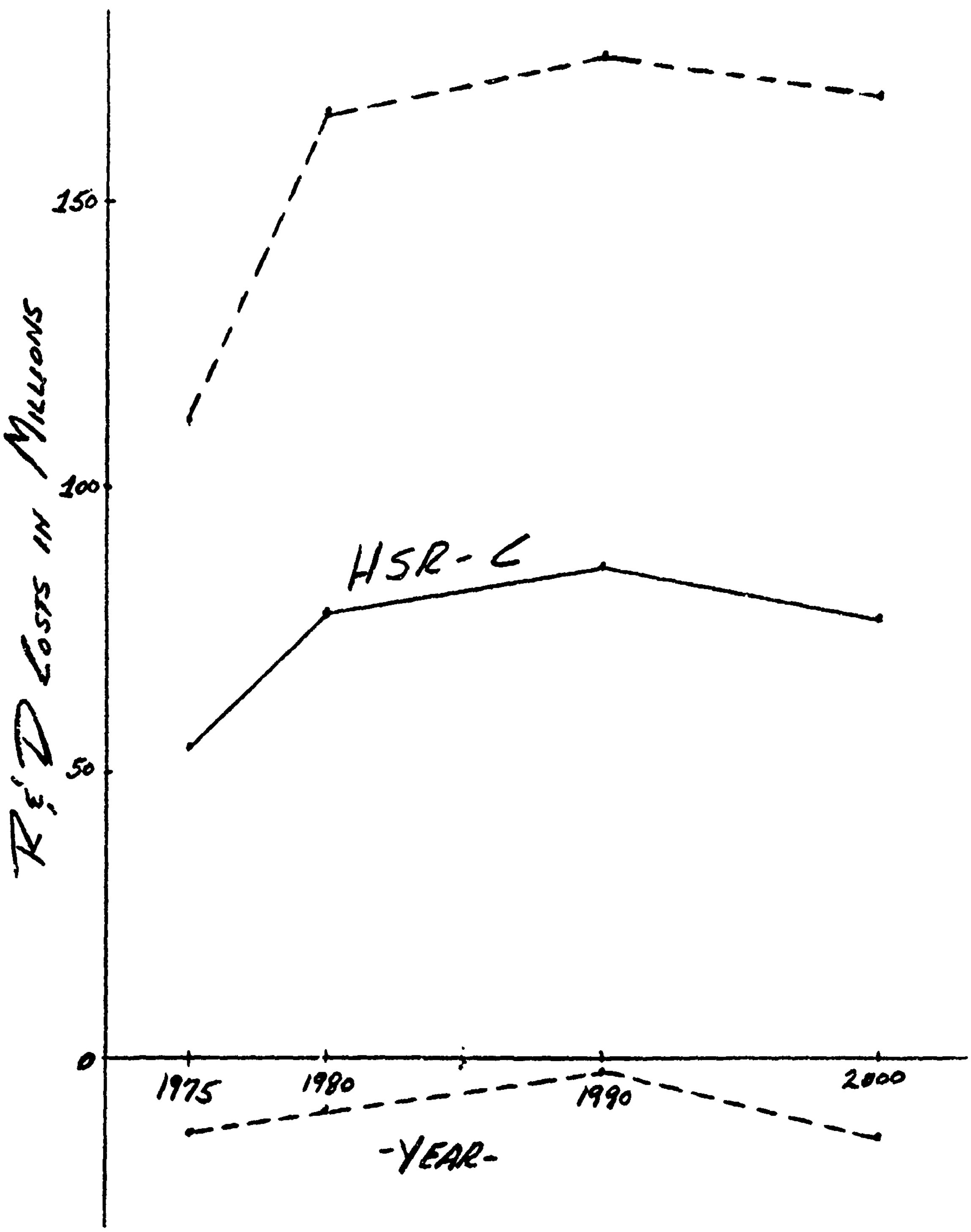

INTERURBAN SYSTEM
HSR-A
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
1975
1980
1990
2000
-YEAR-

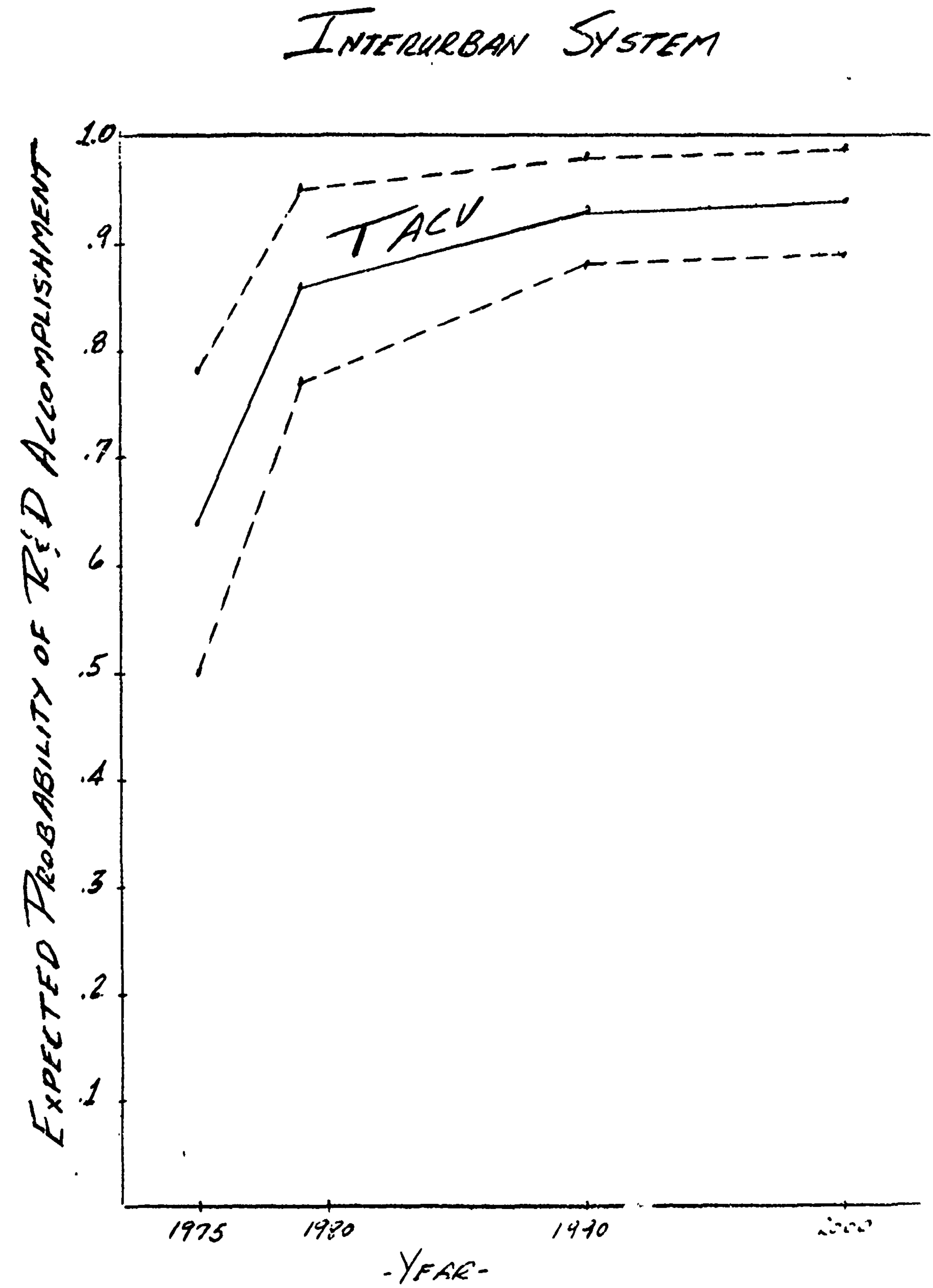
INTERURBAN SYSTEM

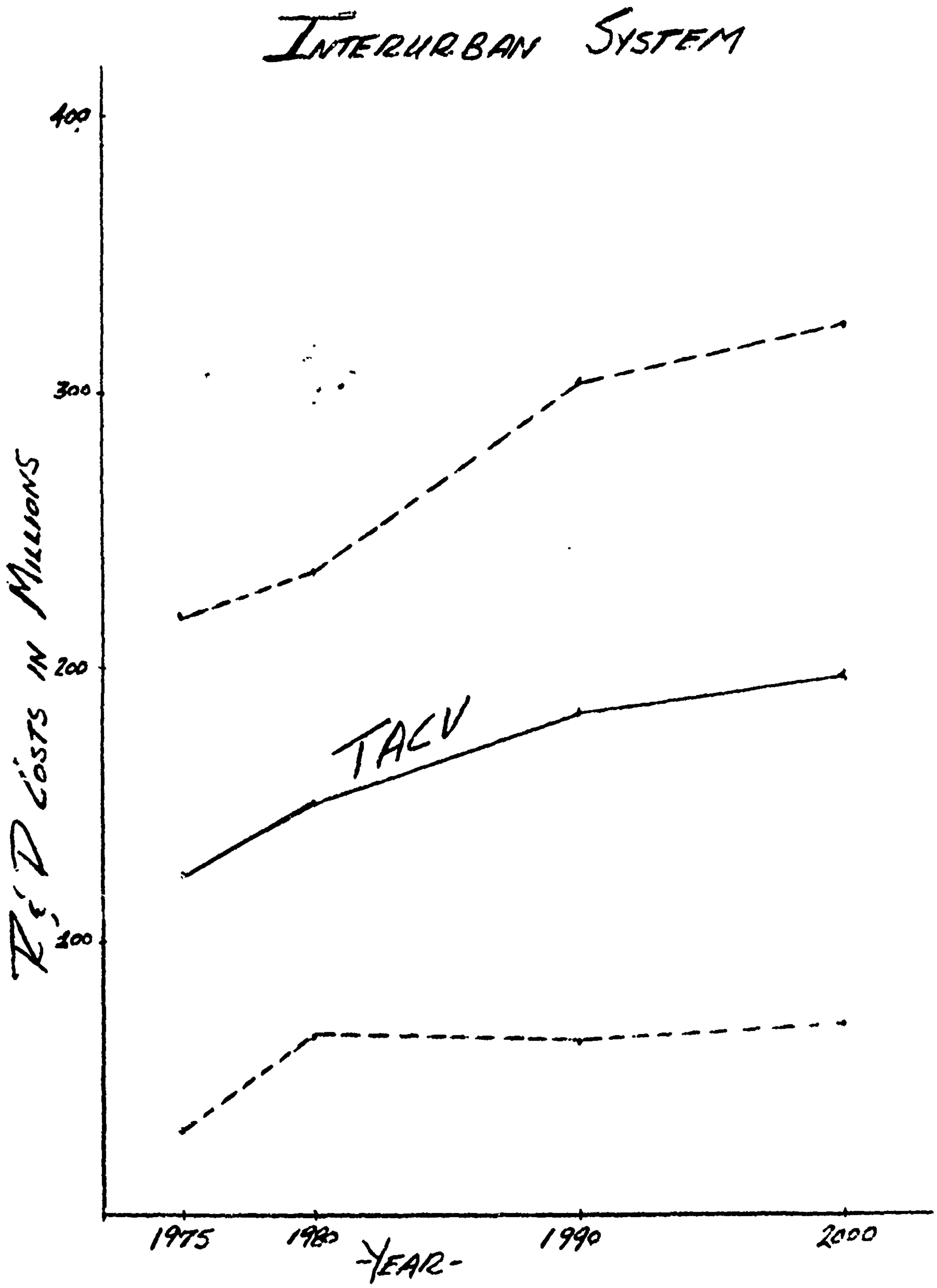



INTERURBAN SYSTEM
HSR-C
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1.0
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
1975
1980
1990
2000
-YEAR-

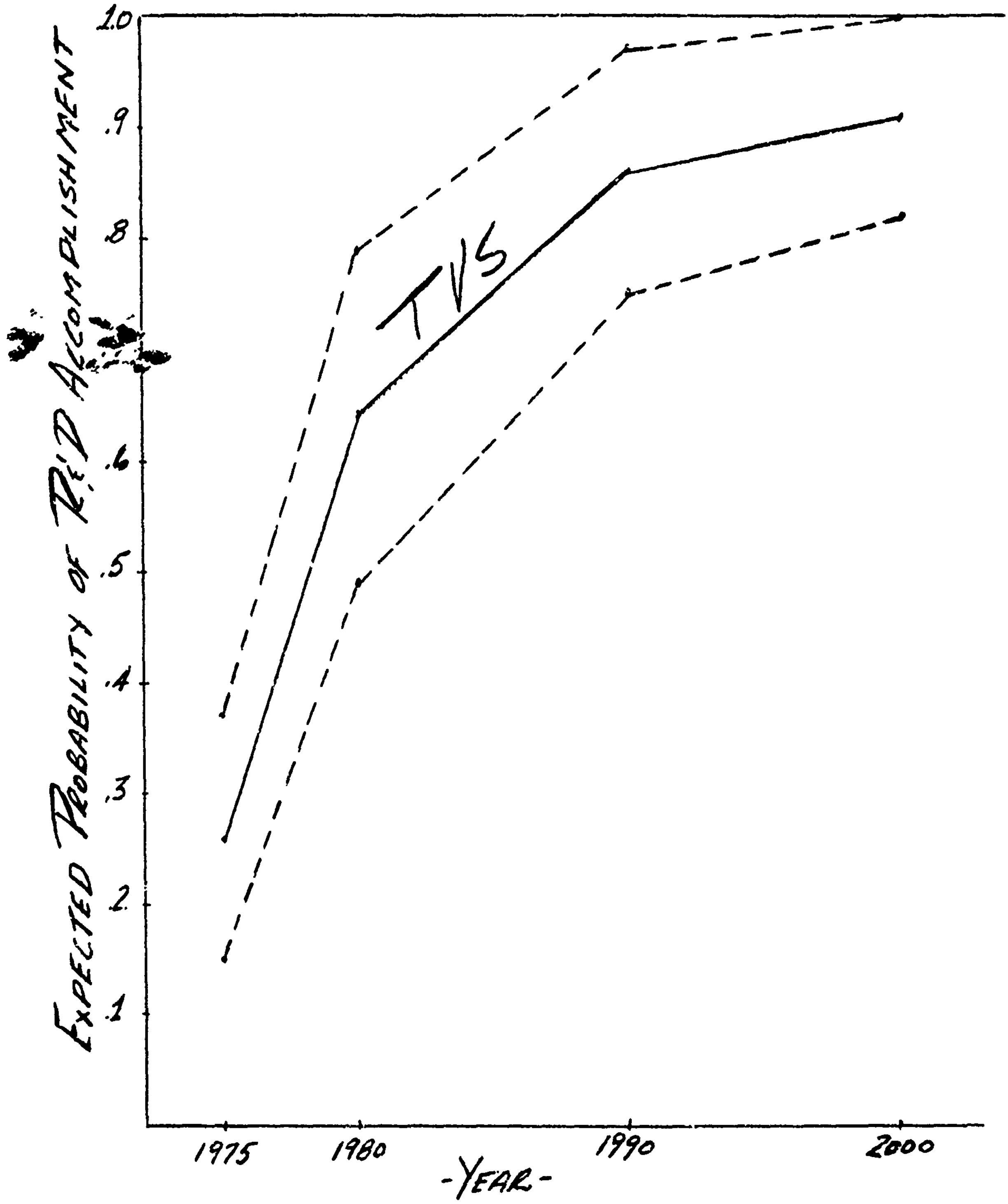
INTERURBAN SYSTEM

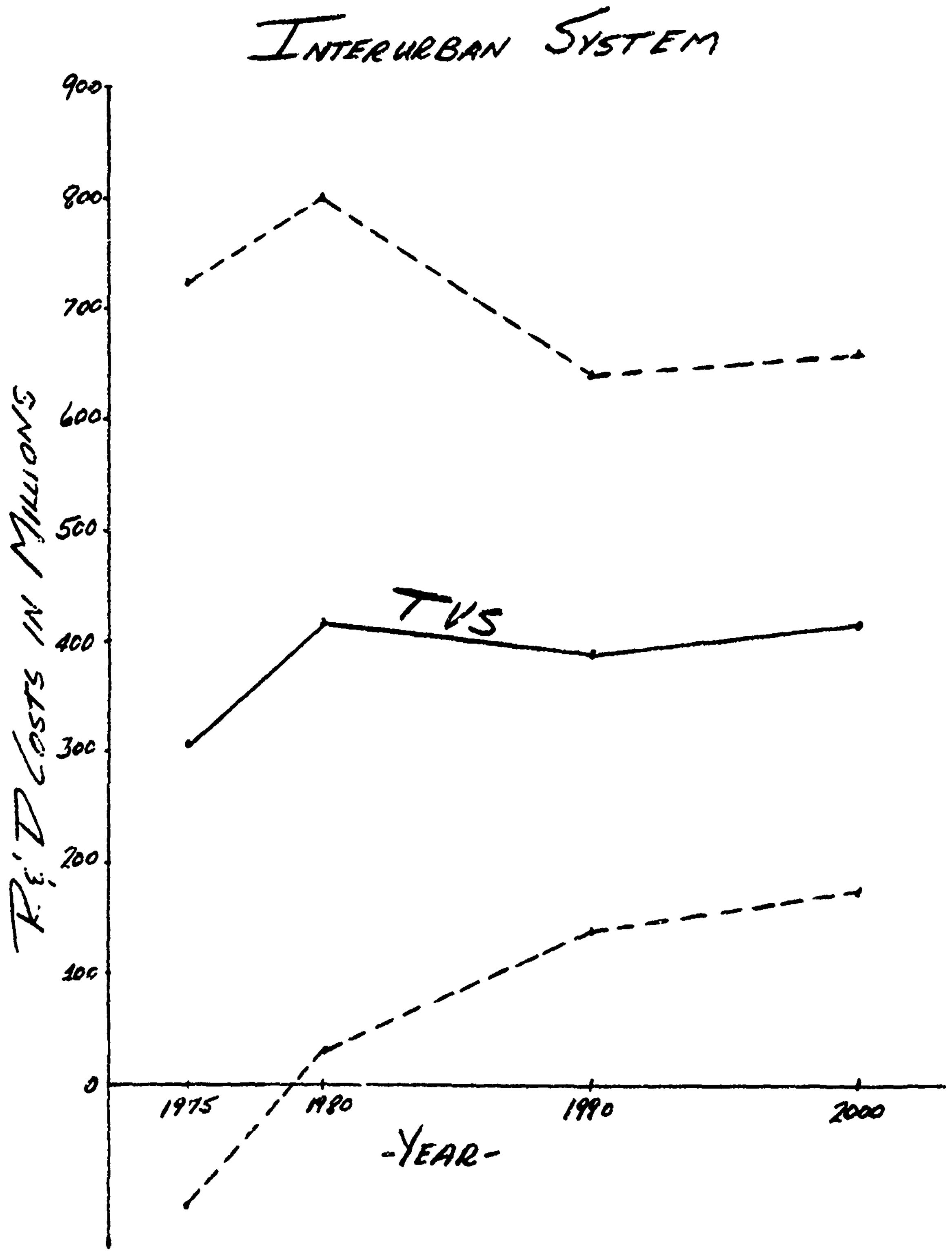



INTERURBAN SYSTEM
TACV
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
1975
1980
1990
2000
-YEAR-

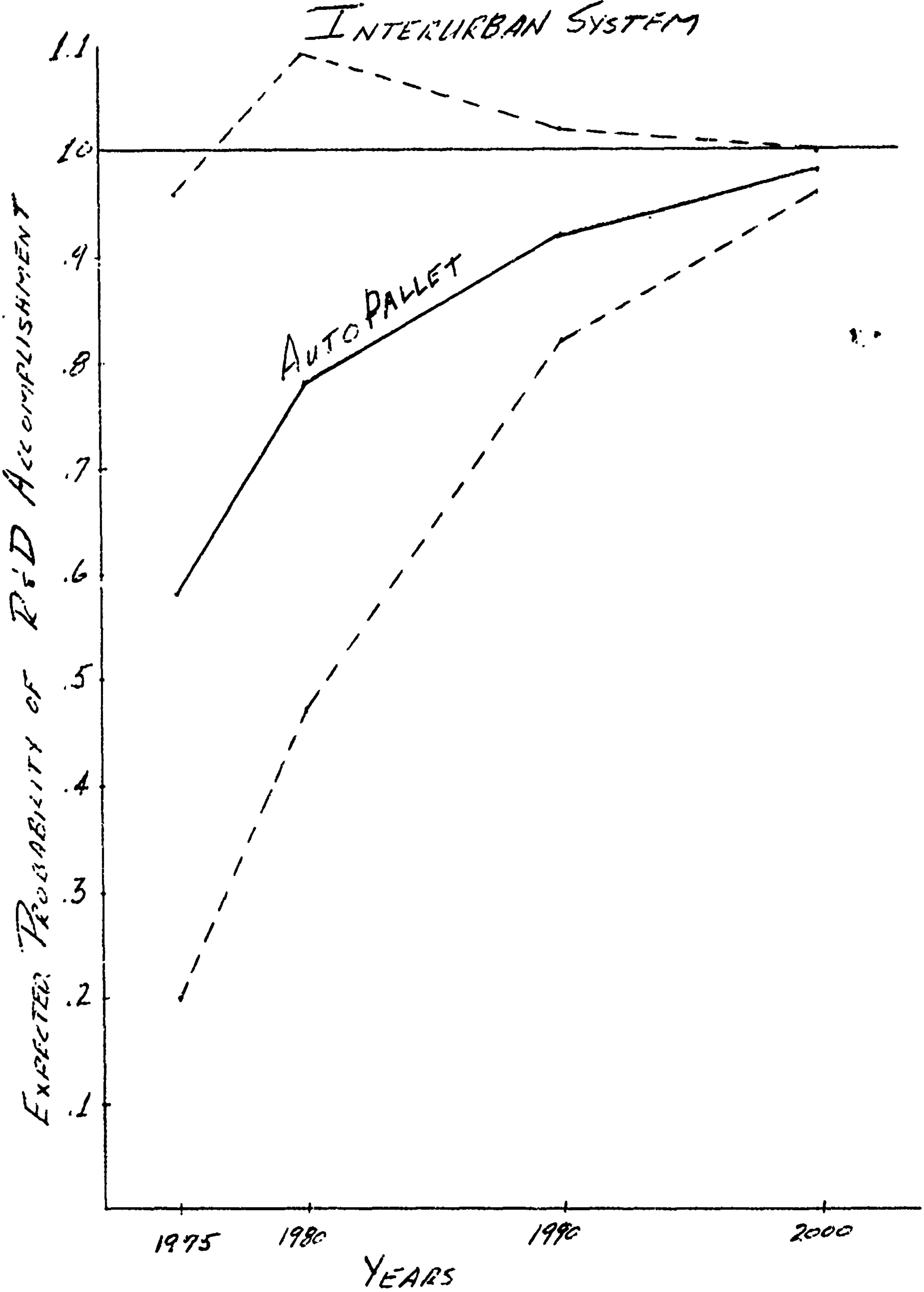

INTERURBAN SYSTEM
R & D COSTS IN MILLIONS
400
300
200
100
TACV
1975
1980
1990
2000
-YEAR-

INTERURBAN SYSTEM

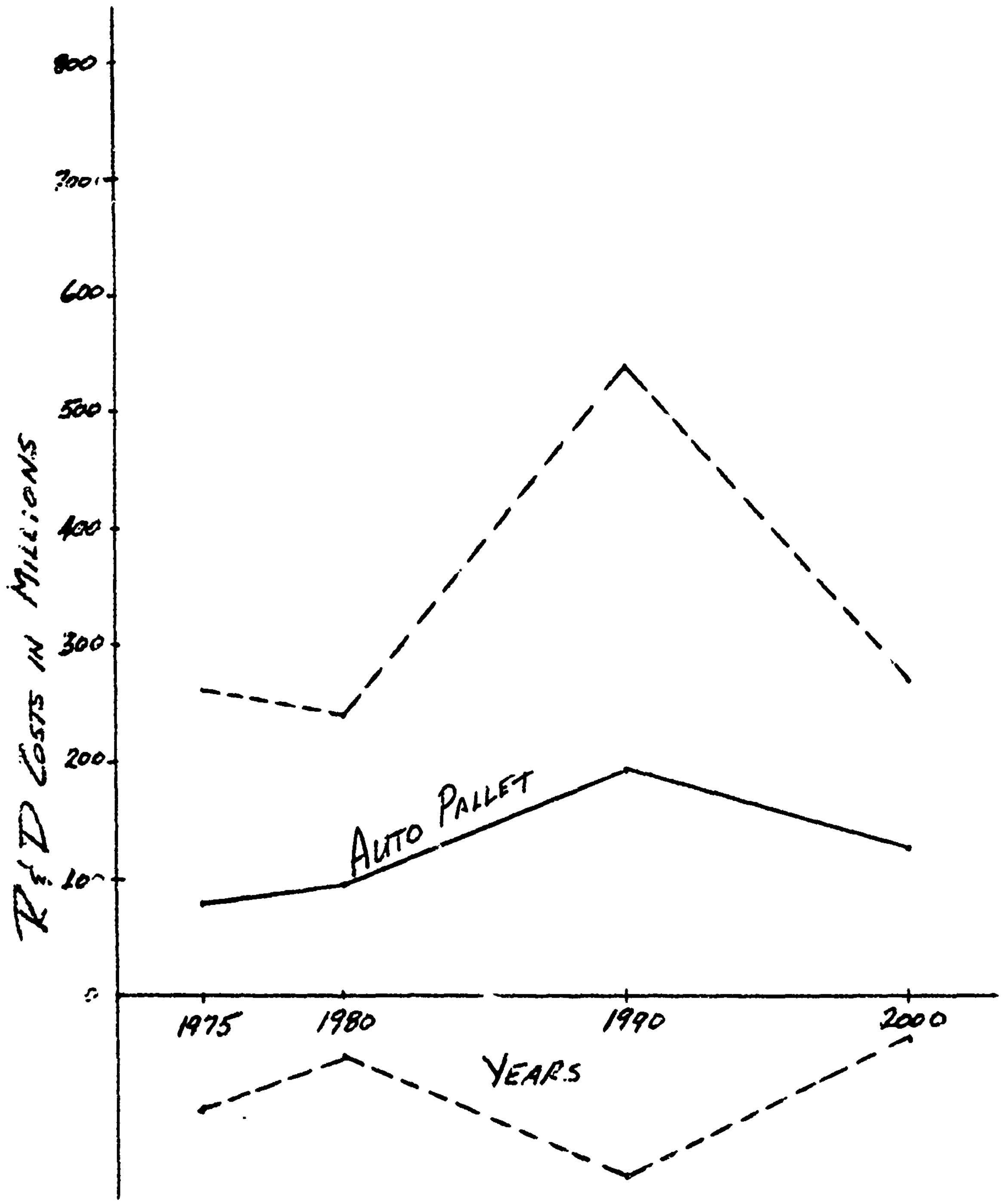




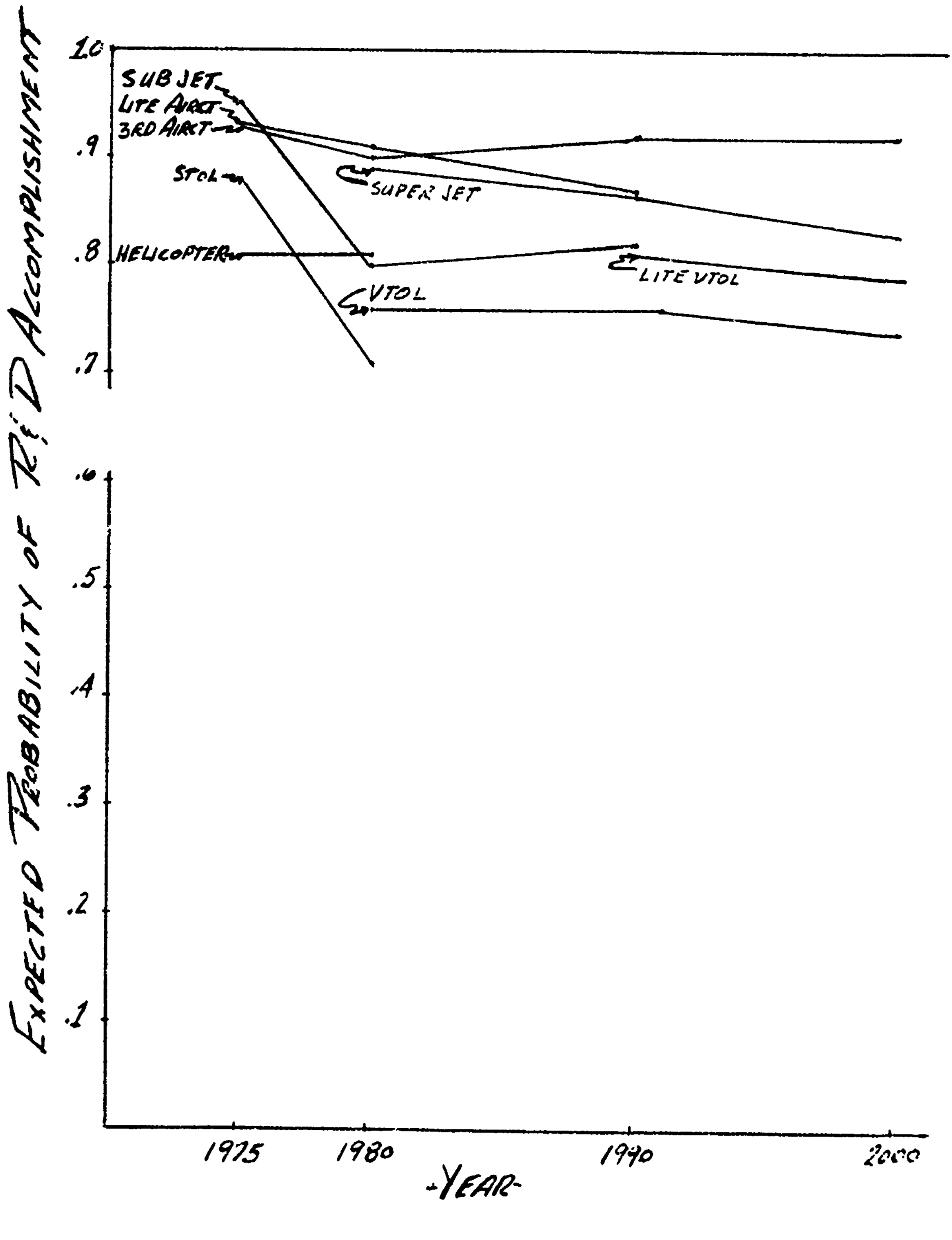
INTERURBAN SYSTEM
900
800
700
600
500
400
300
200
100
0
R & D COSTS IN MILLIONS
TVS
1975
1980
1990
2000
-YEAR-


INTERURBAN SYSTEM
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
AUTO PALLET
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1975
1980
1990
2000
YEARS

INTERURBAN SYSTEM

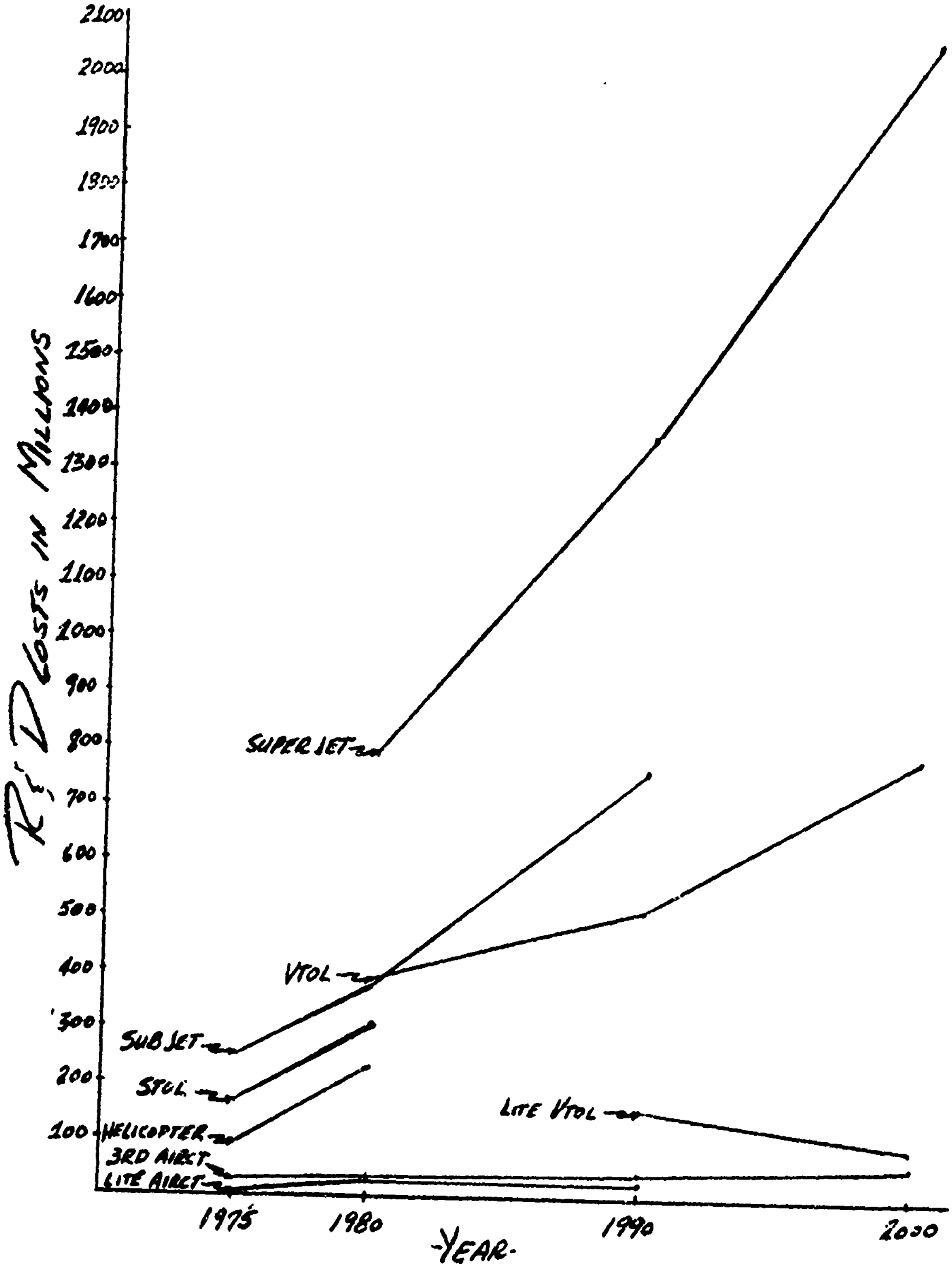


AIR SYSTEMS



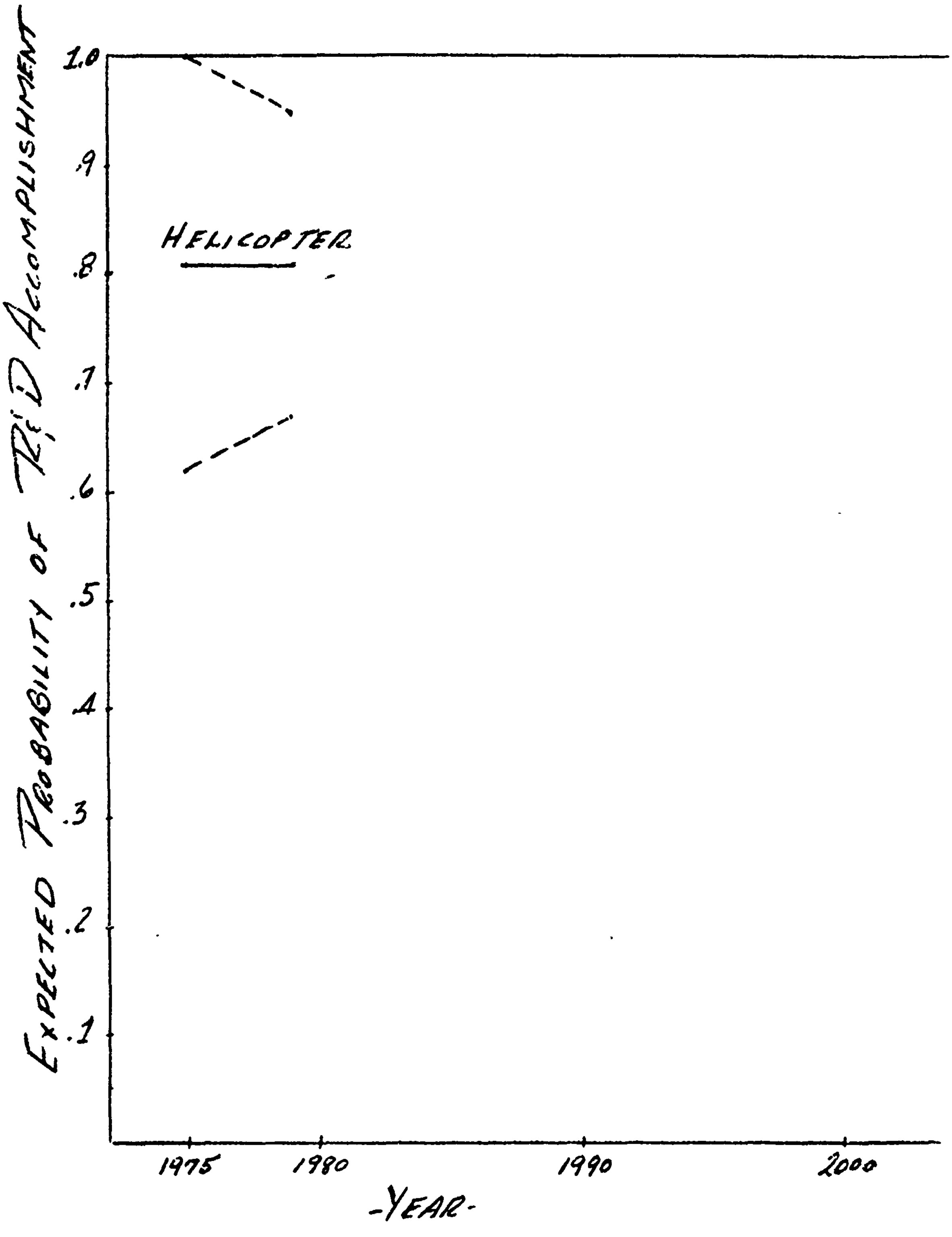
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
SUB JET
LITE AIRCT
3RD AIRCT
STOL
HELICOPTER
SUPER JET
VTOL
LITE VTOL
1975
1980
1990
2000
-YEAR-

AIR SYSTEMS



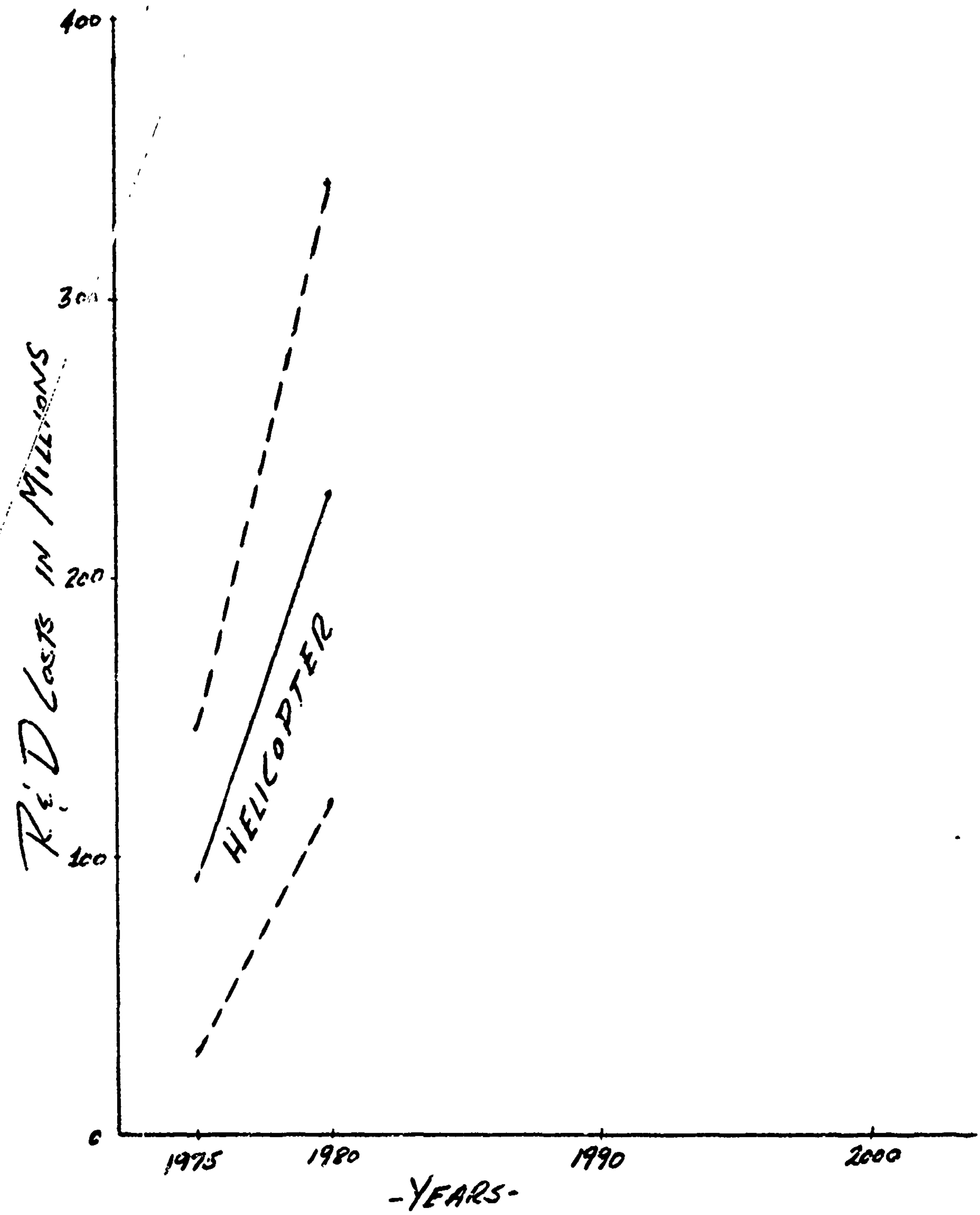
R & D COSTS IN MILLIONS
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
SUPER JET
VTOL
SUB JET
STOL
HELICOPTER
3RD AIRCT
LITE AIRCT
LITE VTOL
1975
1980
1990
2000
-YEAR-

AIR SYSTEM

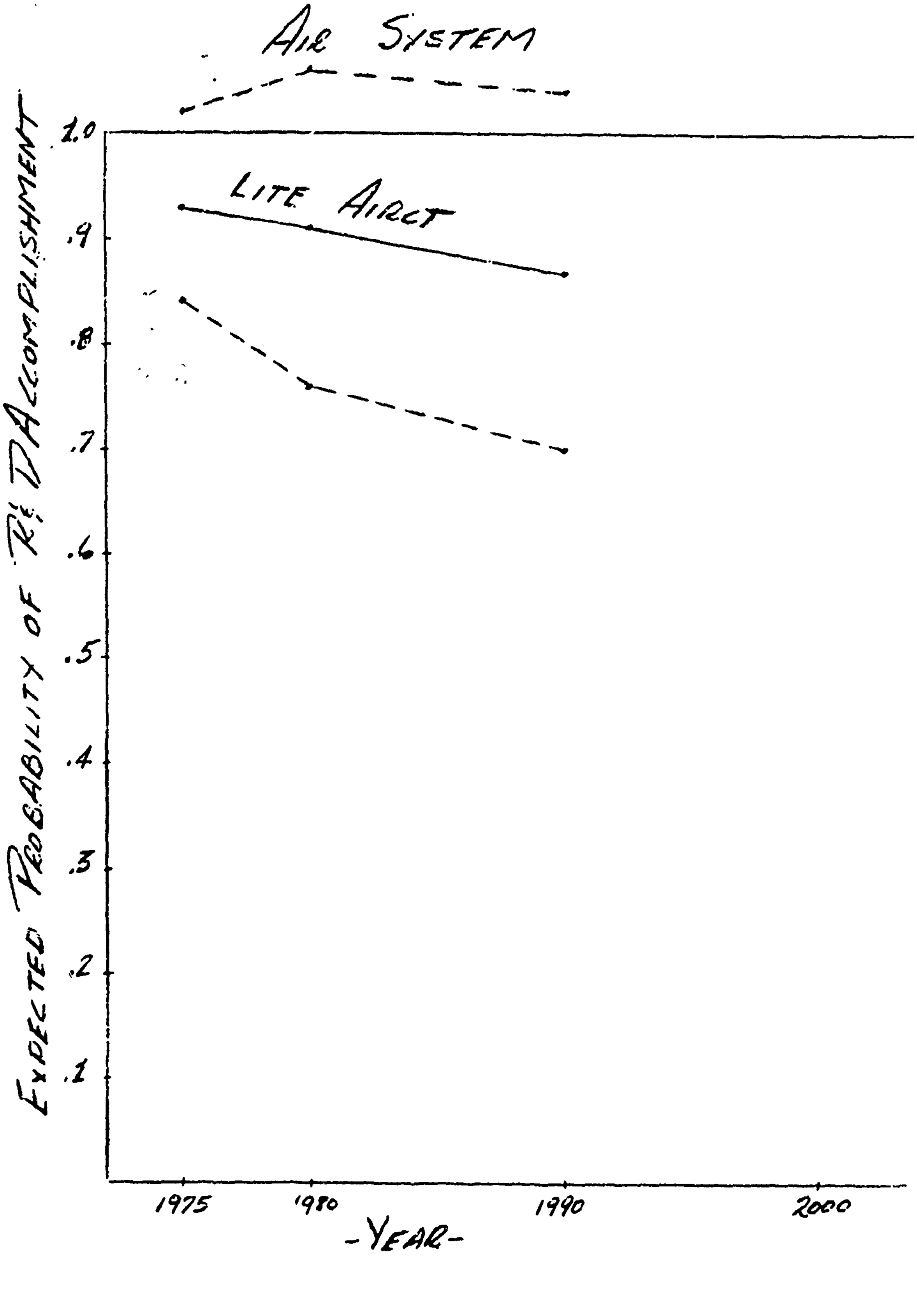


EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
HELICOPTER
1975
1980
1990
2000
-YEAR-

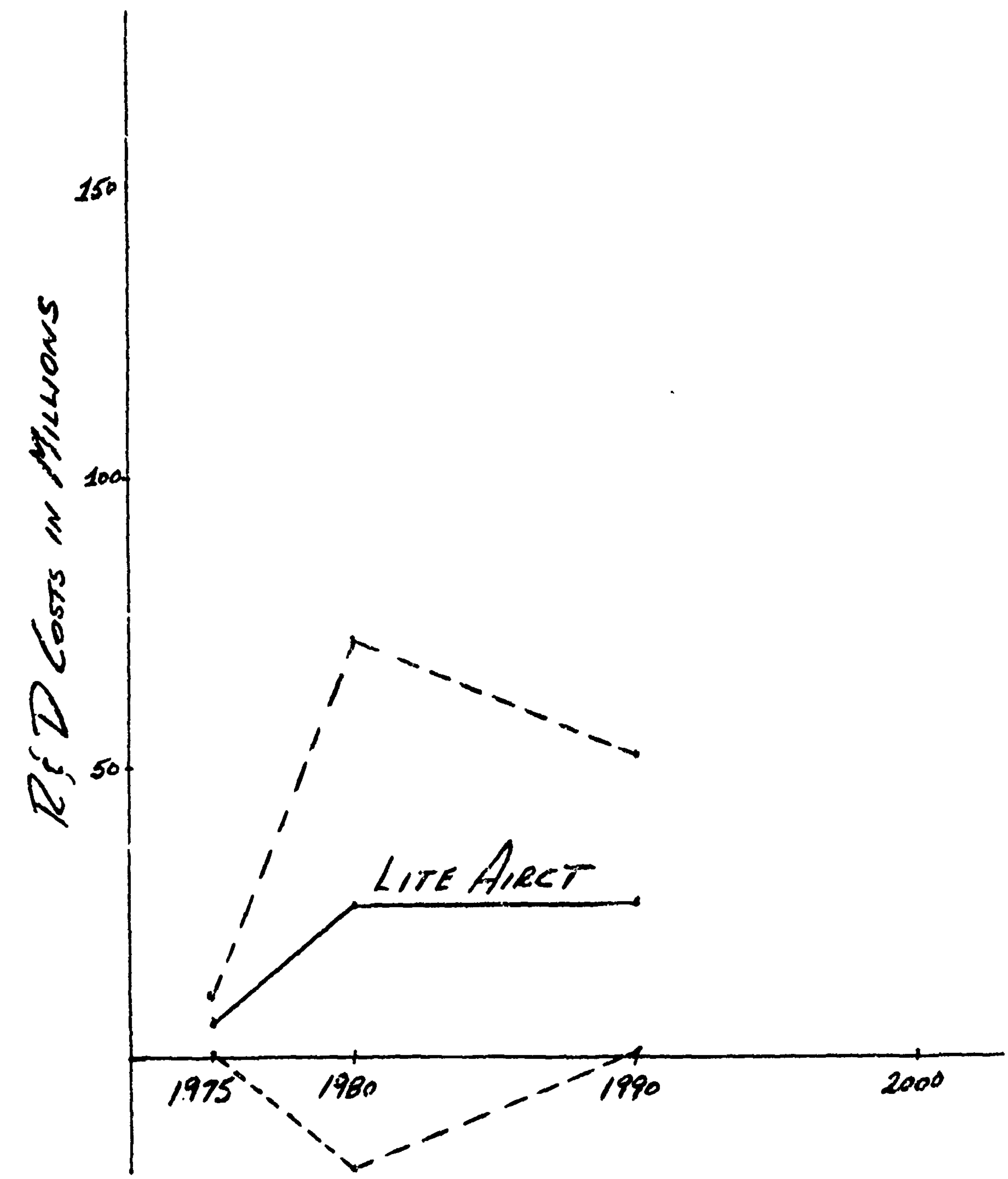
AIR SYSTEM



400
300
200
100
0
R & D COSTS IN MILLIONS
HELICOPTER
1975
1980
1990
2000
-YEARS-

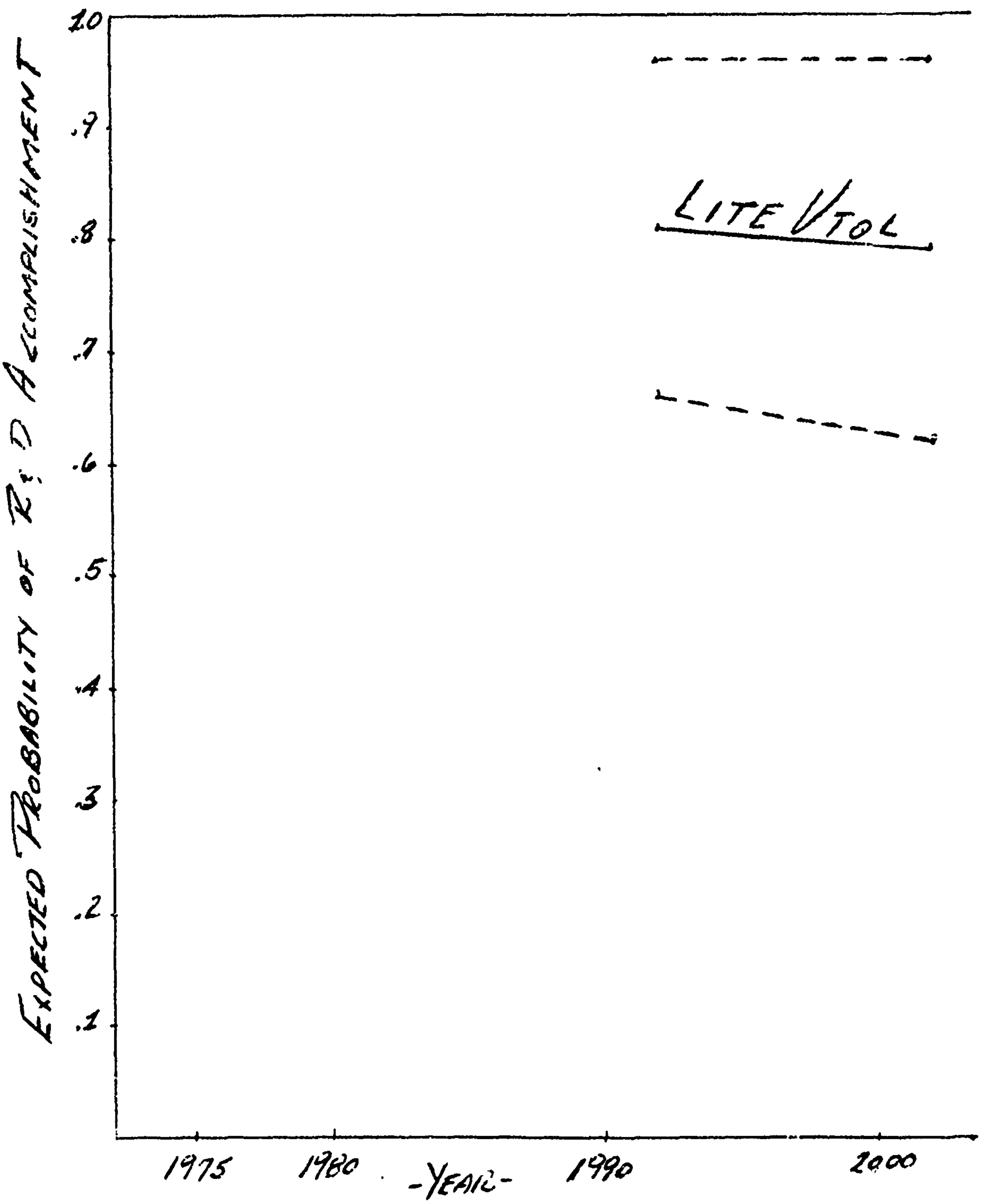

AIR SYSTEM
LITE AIRCT
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
1975
1980
1990
2000
-YEAR-

AIR SYSTEM

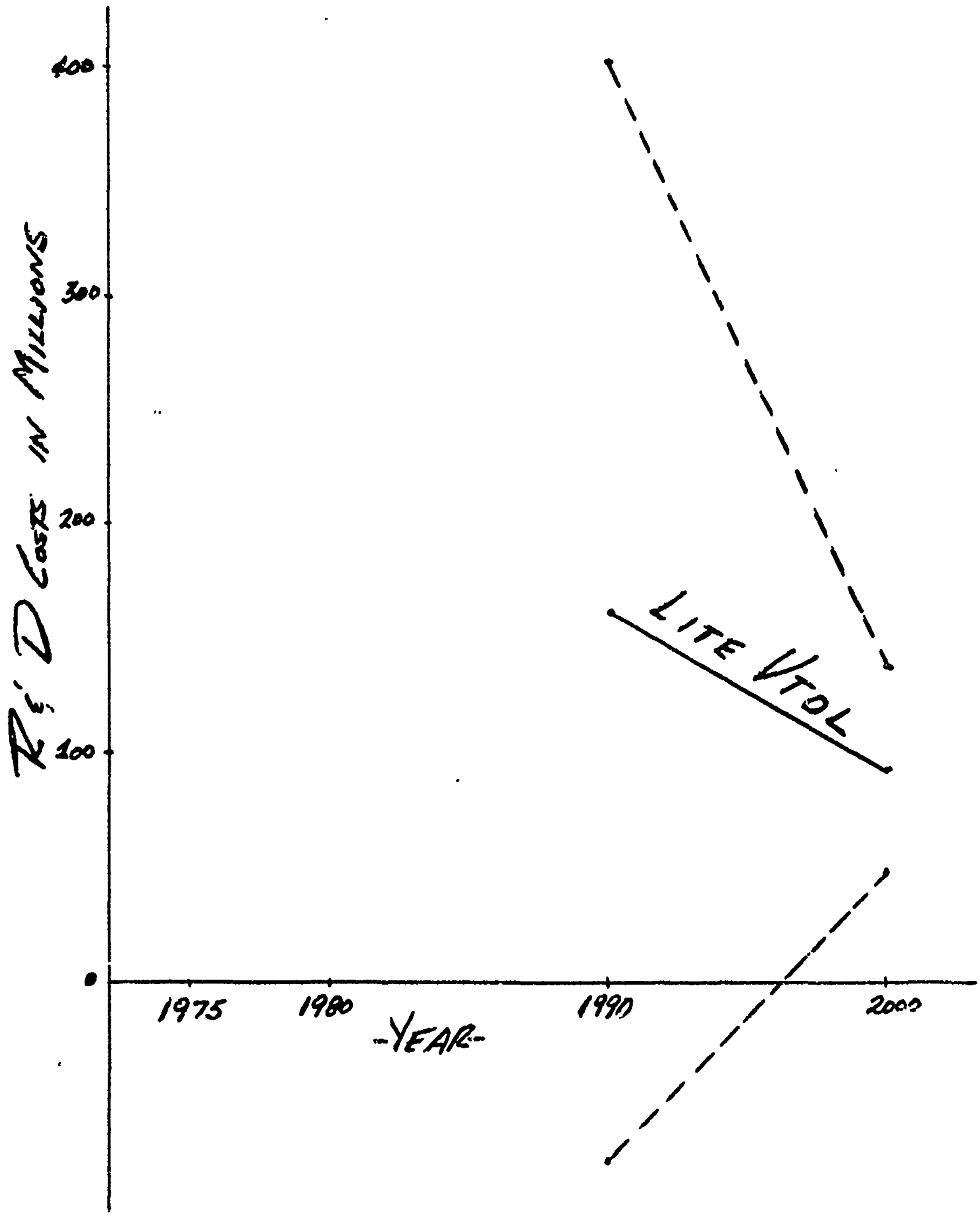


R&D COSTS IN MILLIONS
150
100
50
LITE AIRCT
1975
1980
1990
2000

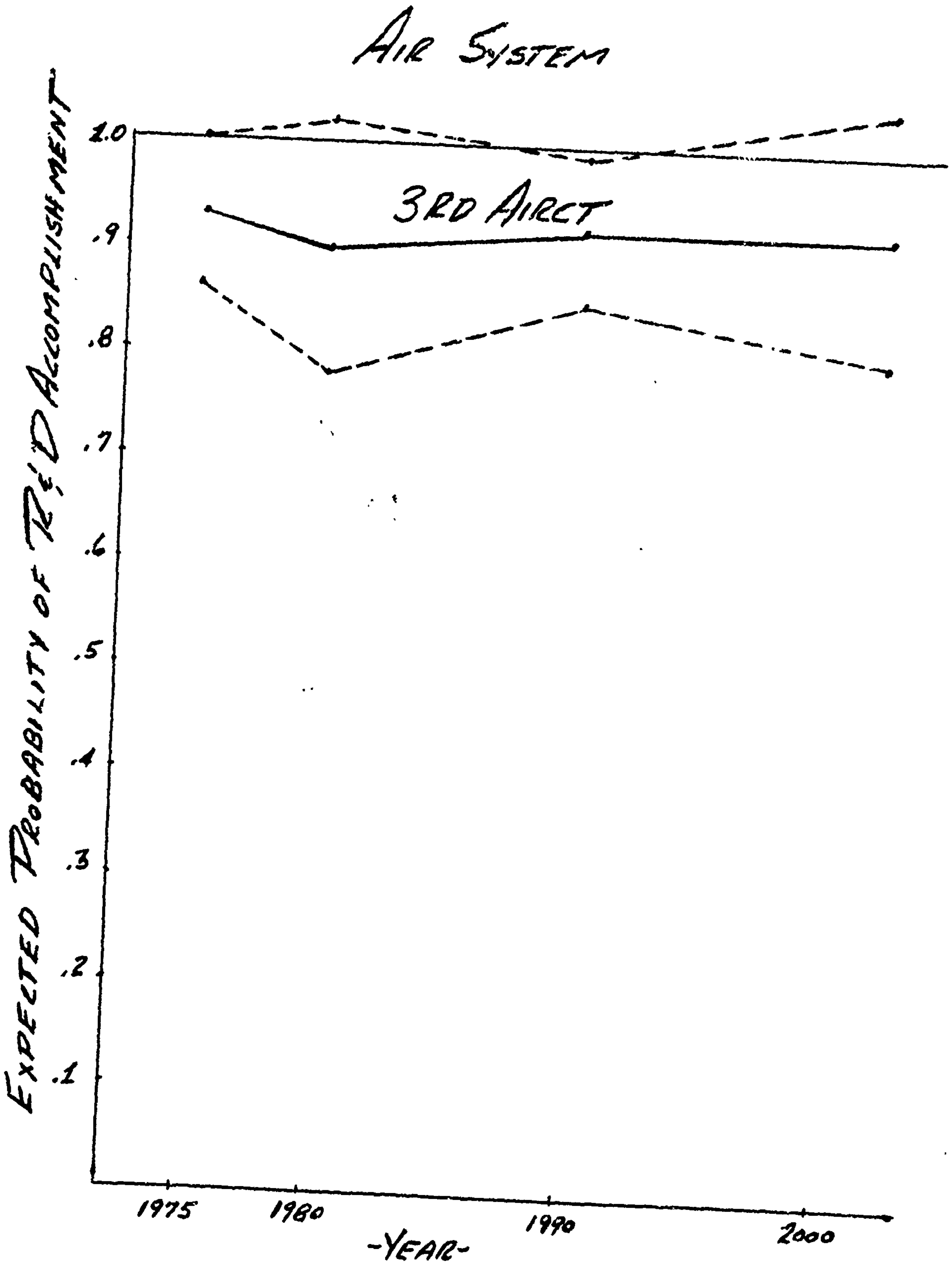
AIR SYSTEM


1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
EXPECTED PROBABILITY OF R & D ACCOMPLISHMENT
LITE VTOL
1975
1980
-YEAR-
1990
2000

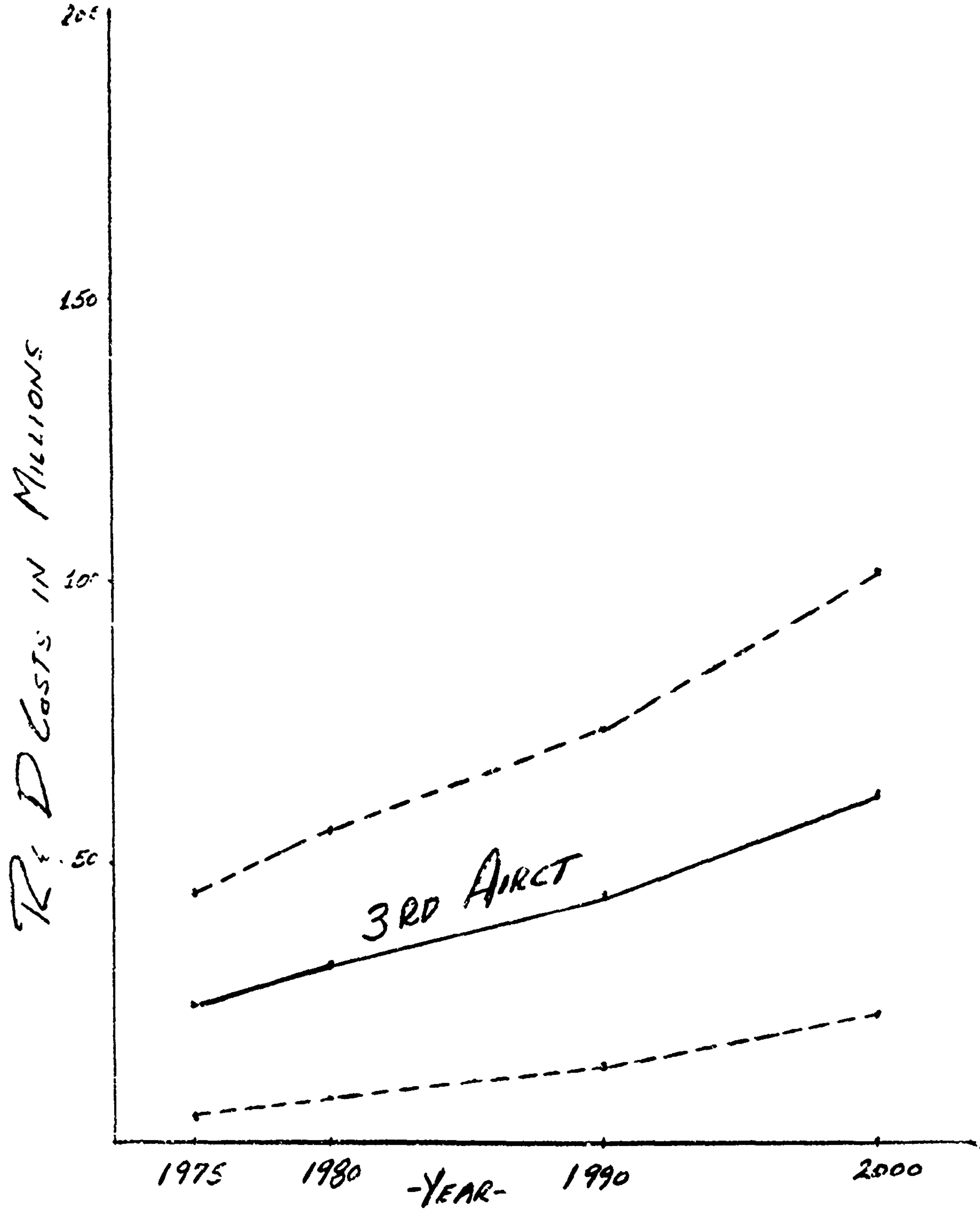
AIR SYSTEM



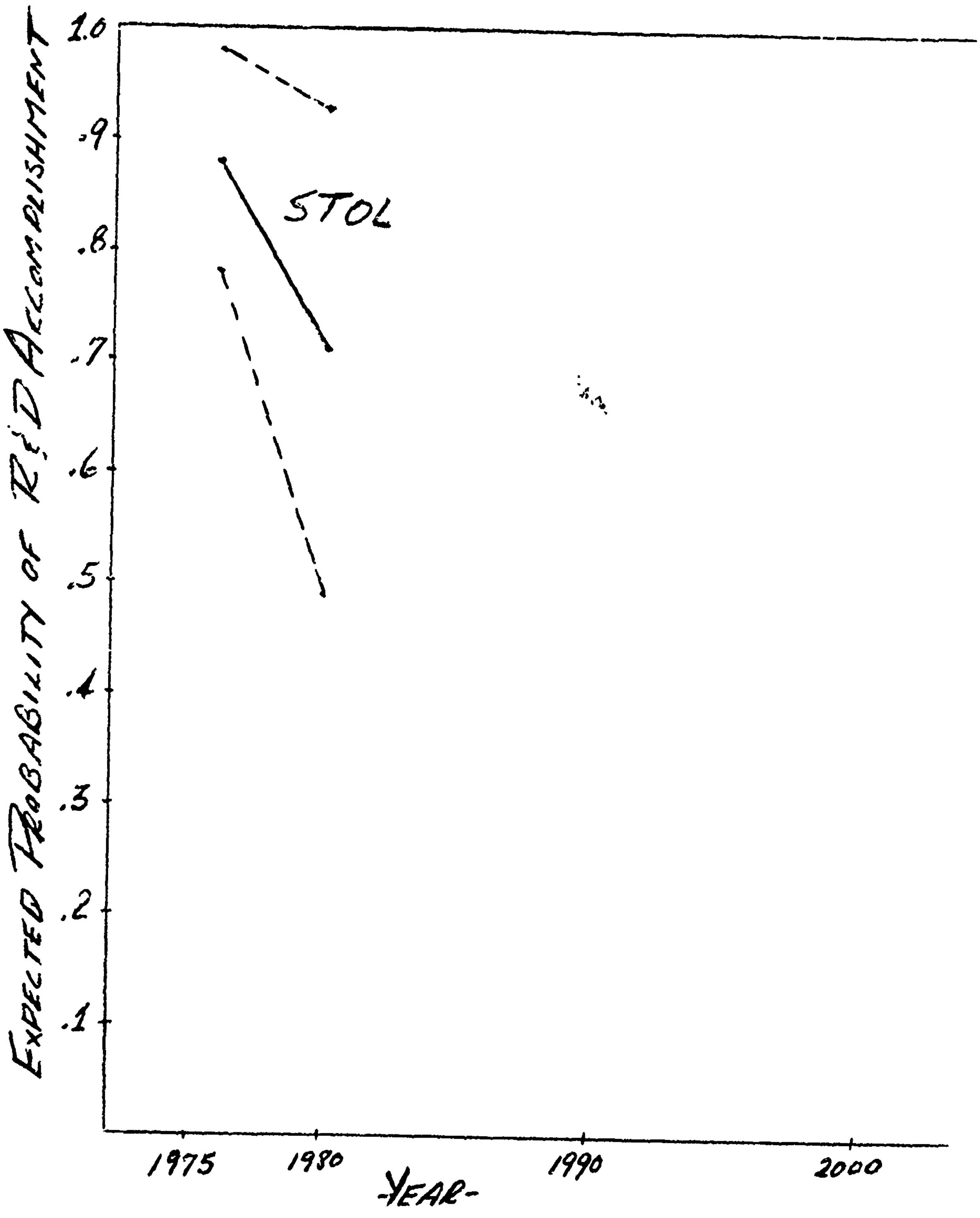
R & D COSTS IN MILLIONS
400
300
200
100
0
LITE VTOL
1975
1980
1990
2000
-YEAR-


AIR SYSTEM
3RD AIRCT
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
1975
1980
1990
2000
-YEAR-

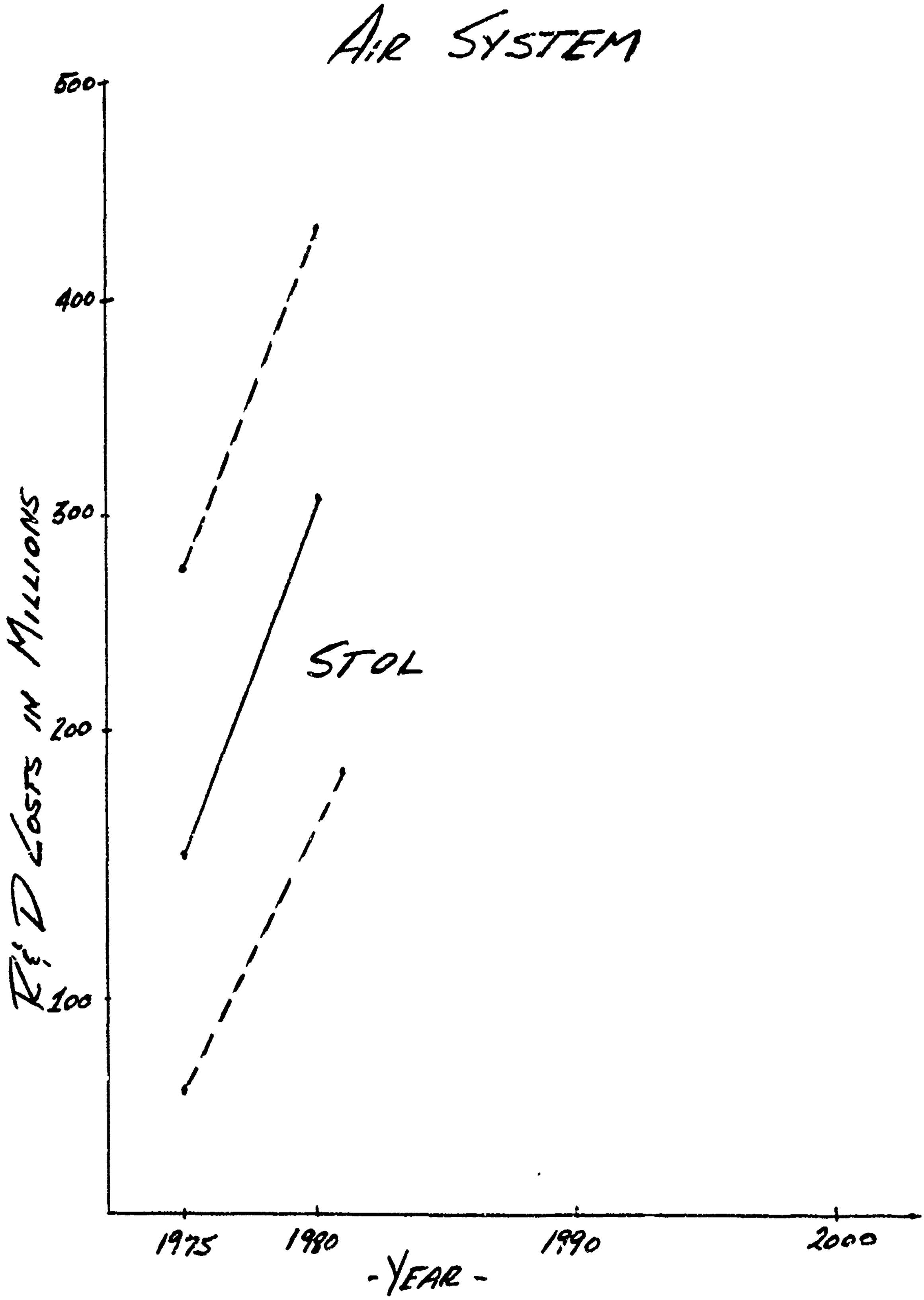
AIR SYSTEM

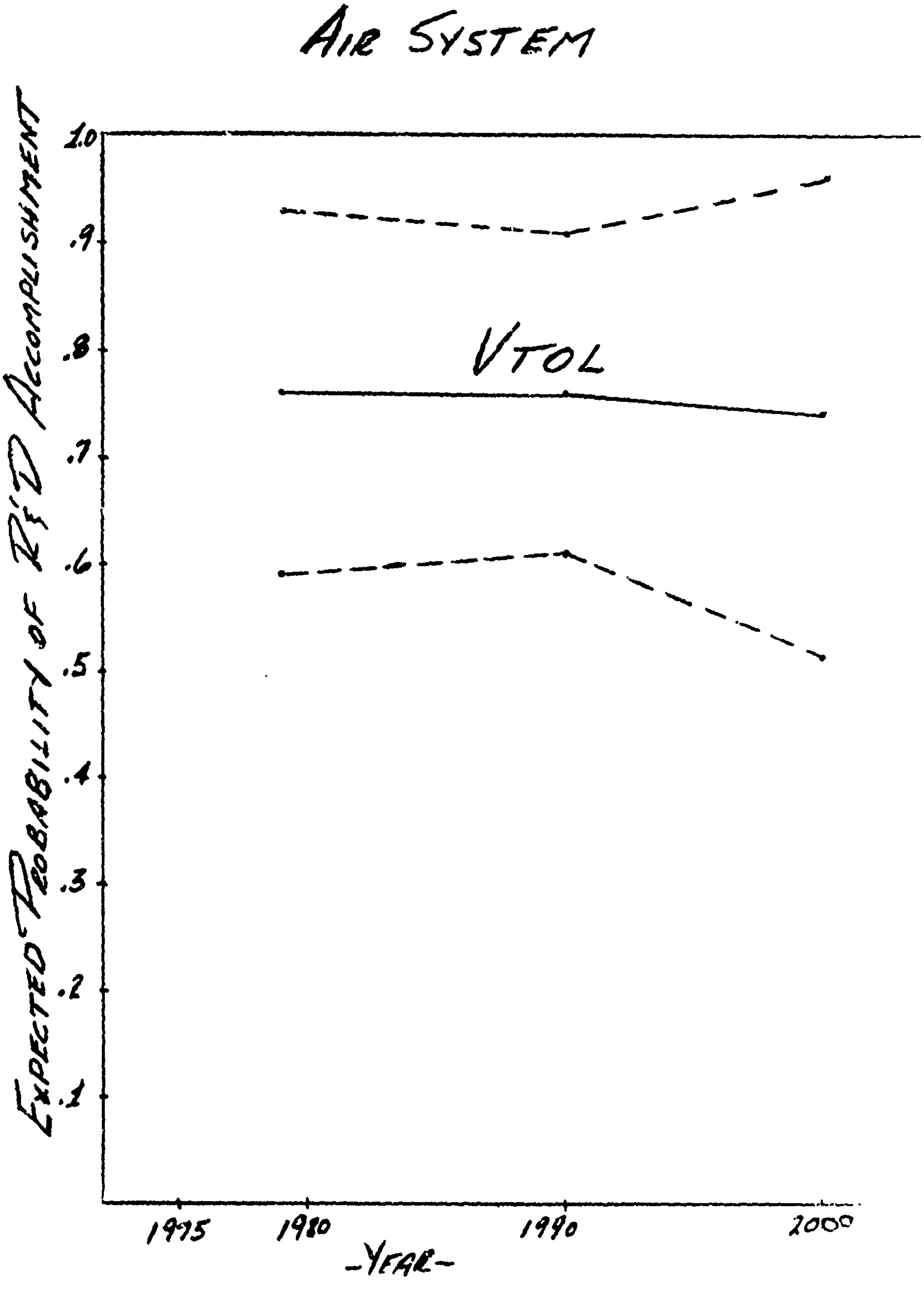

200
150
100
50
R&D COSTS IN MILLIONS
3RD AIRCT
1975
1980
1990
2000
-YEAR-

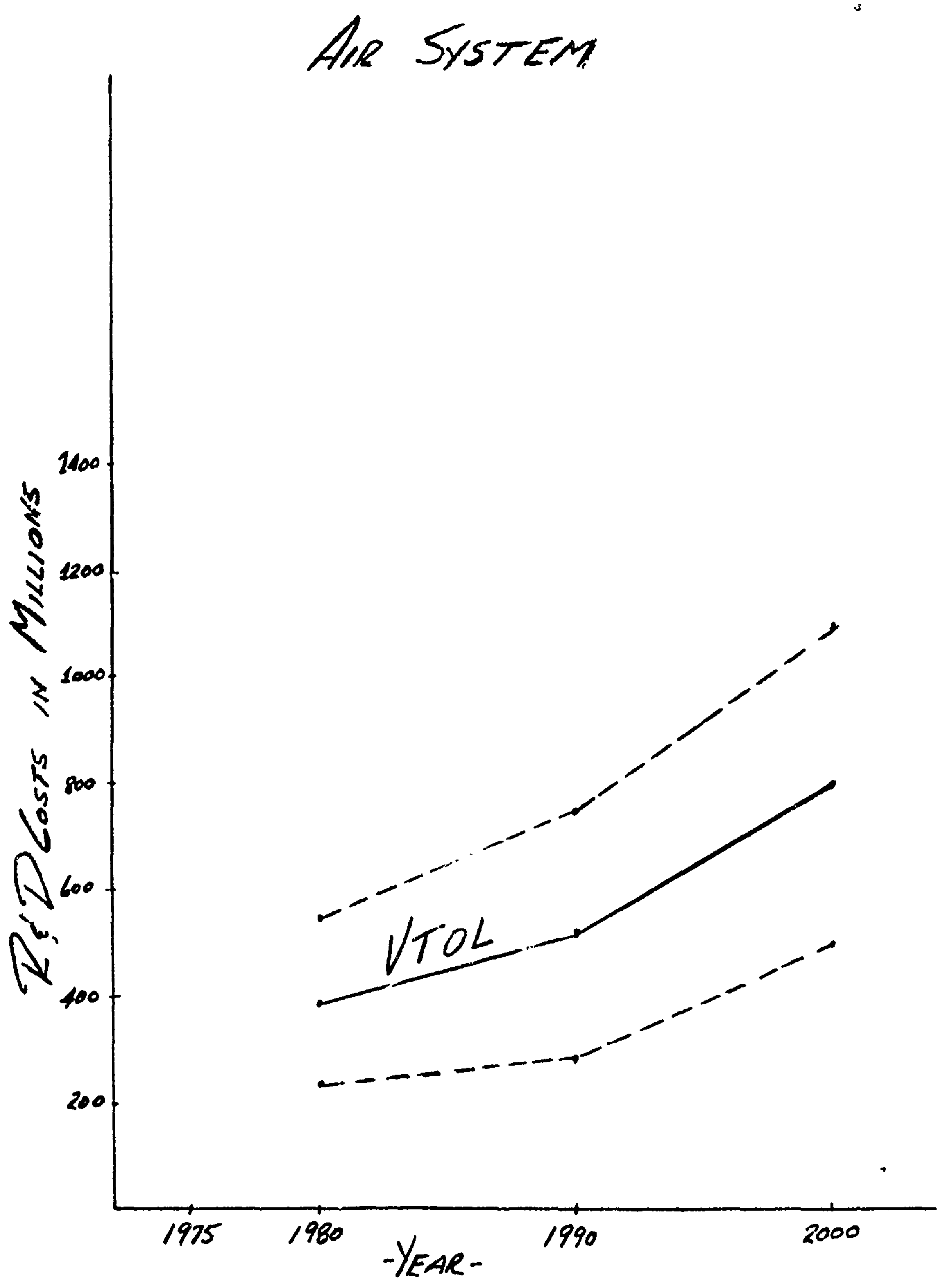
AIR SYSTEM

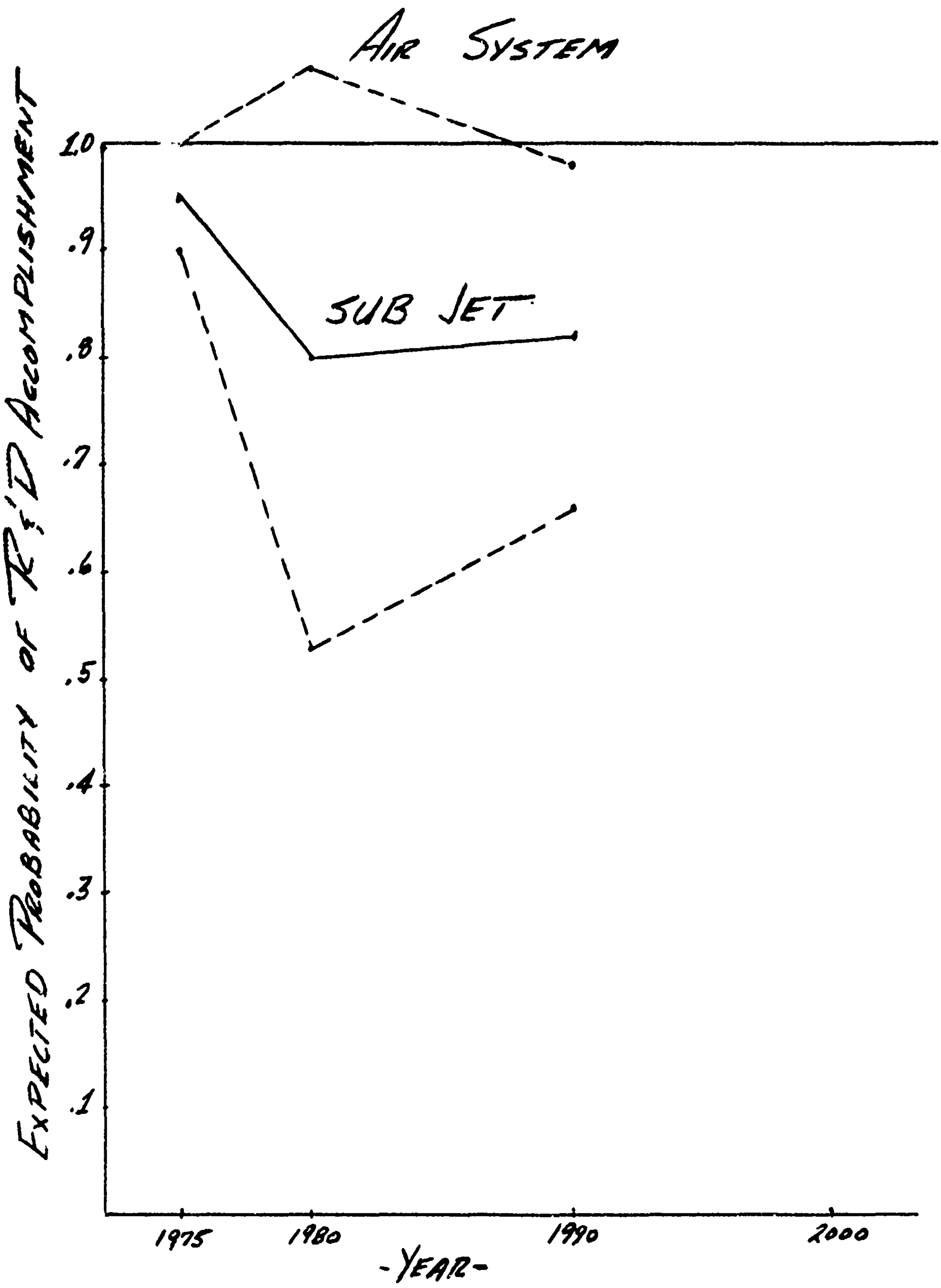


EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
STOL
1975
1980
1990
2000
-YEAR-

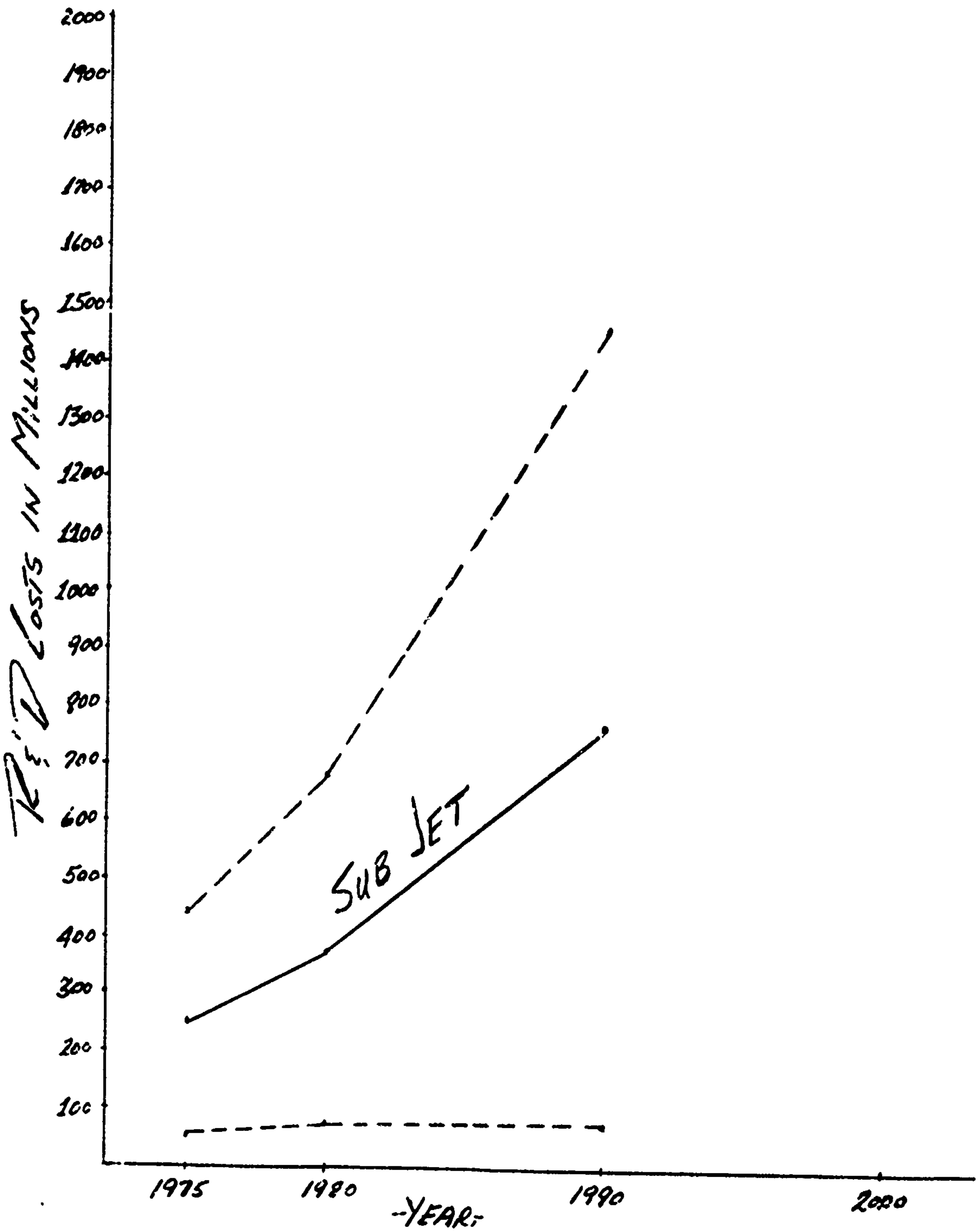

AIR SYSTEM
500
400
300
200
100
R & D COSTS IN MILLIONS
STOL
1975
1980
1990
2000
- YEAR -

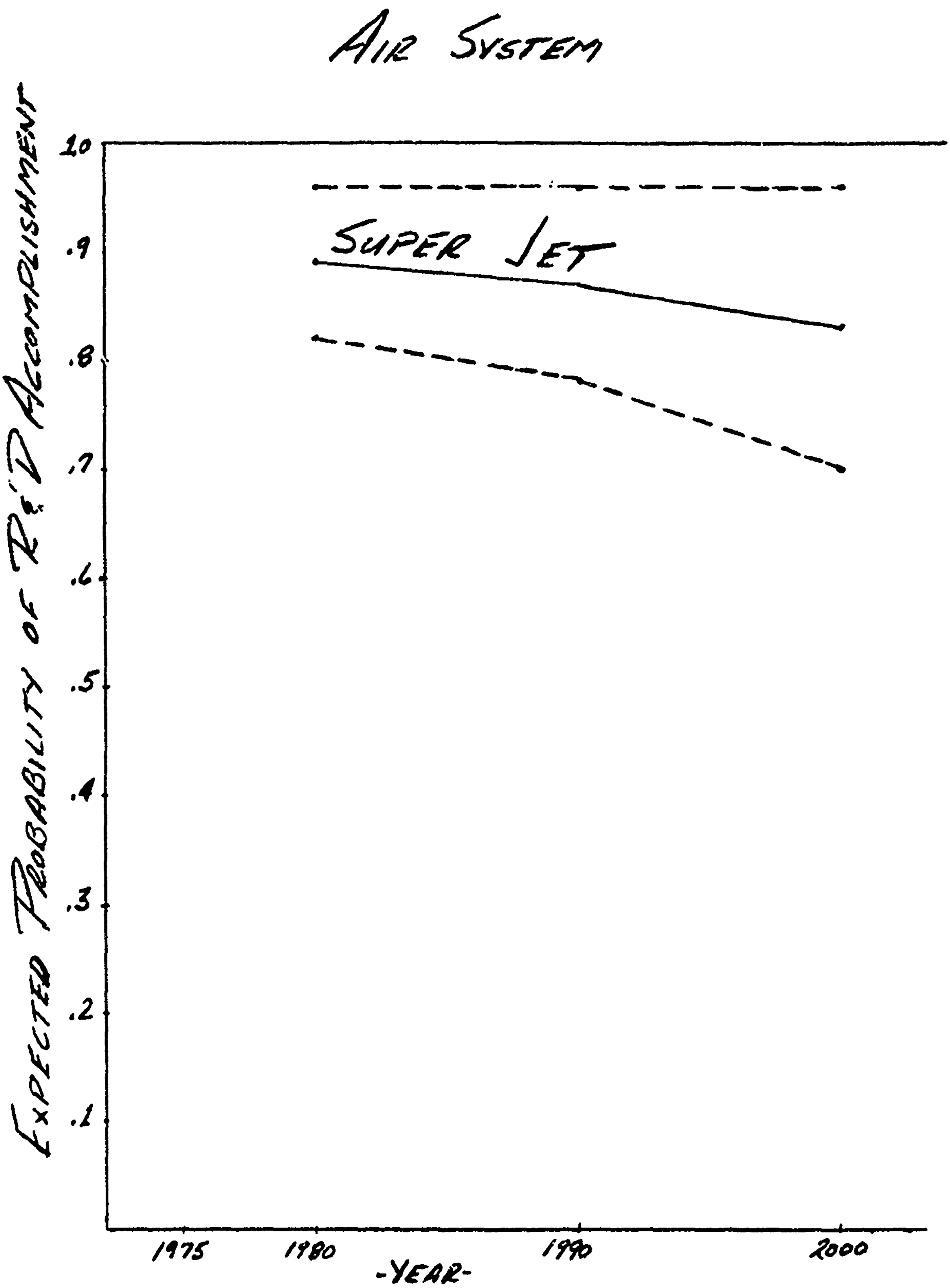

AIR SYSTEM
VTOL
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
1975
1980
1990
2000
-YEAR-


AIR SYSTEM
R&D COSTS IN MILLIONS
1400
1200
1000
800
600
400
200
VTOL
1975
1980
1990
2000
-YEAR-

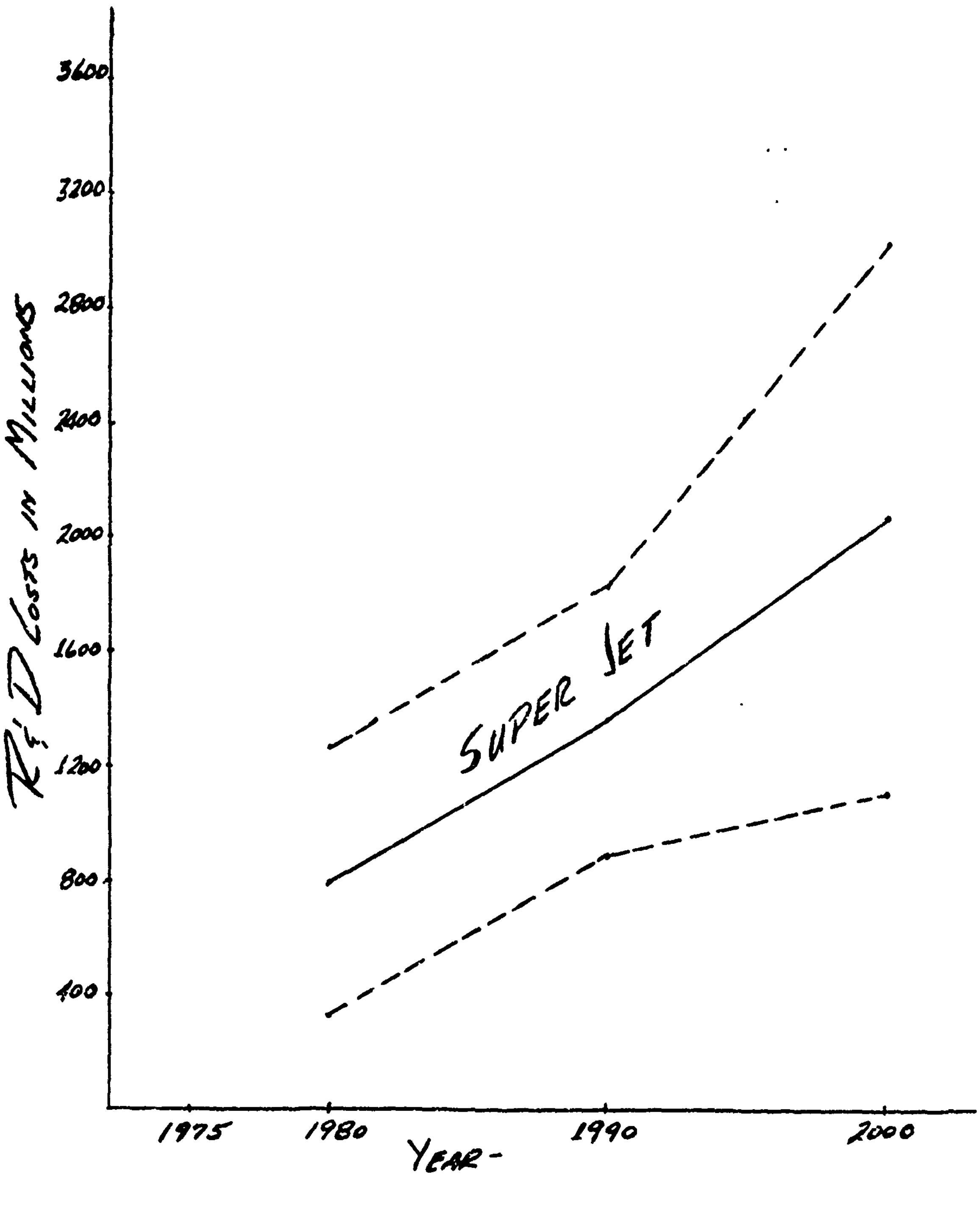

AIR SYSTEM
SUB JET
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
1975
1980
1990
2000
-YEAR-

AIR SYSTEM


2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
R&D COSTS IN MILLIONS
SUB JET
1975
1980
1990
2000
-YEAR-


AIR SYSTEM
SUPER JET
EXPECTED PROBABILITY OF R&D ACCOMPLISHMENT
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
1975
1980
1990
2000
-YEAR-

AIR SYSTEM



3600
3200
2800
2400
2000
1600
1200
800
400
R&D COSTS IN MILLIONS
SUPER JET
1975
1980
1990
2000
YEAR-

APPENDIX 4

Appendix 4

A. General

1. This appendix includes information describing:

   - System parameters for the modal split,
   - Rules used to determine system access/egress times and distances, and Air Mile ÷ Mode Mile ratios (C_1).
   - Sampling Routine for obtaining Base Year Systems Block Velocities.

B. System Parameters

1. Before a modal split forecast computer run can be made, about 24 input data parameters have to be defined. These parameters cover information peculiar both to

   - The operational and cost characteristics of the systems available for choice, and
   - The attributes which define a trip as a total system (i.e. portal to portal).

   Examples of the data required for the 1 passenger - group (1 passenger - time value) runs are attached as a series of formatted input sheets. Each sheet contains parametric descriptions of the systems that could be available at a particular distance in an urban, non urban, or other environment. The first sheet defines qualitatively the meaning of each input parameter.* Notes describing any exceptions follow the formatted inputs.

---

* More detailed explanation of the input parameters is contained in the original NASA Time Value Modal Split Model report by H. M. Drake and others (See References).

C. Access/Egress Times and Distances

1. Access and Egress Times

a. These are assumed time expenditures to account for the time used during the interface portions of a one way trip (Figure L page 86, main report). There are many access/egress possibilities, but for this report they were limited to either walking, kiss and ride auto, or taxi. There is no data available to describe distributions for this information, consequently best judgment of group consensus was used to determine values. An example of the values used for major trip lengths greater than 50 miles is shown on Matrix 4-1. Similar arrays were derived for trip lengths of less than 50 miles.

2. Access and Egress Distances

a. For Auto:

Access and egress distances were assumed to be the average distances required to go from the portal's door to the location of the auto.*

b. For Bus and Rail:

Access and egress distance were assumed to equal 5 miles**

c. For Air:

Access and egress distances were assumed to be 8.2 miles***

* Average auto velocity of 17.5 mph was used.
** Chicago Area Transportation Study Vol. 2, Data Projection, 1960.
*** Official Airline Guide, projected Average Distance for access mode.

D. Procedure for Determining Average Velocity and Air Mile/Mode Mile Ratio

1. As with the access/egress times in the preceding section, very little data has been collected on the average block velocity for conventional modes. In order to achieve this input data the following was achieved:

The top 100 cities (i.e. in terms of the number of originating or terminating domestic airline trips)* were defined for the distance intervals of 20-50 miles, 50-200 miles, 200-500 miles, 500-1000 miles and 1000-3500 miles. For each of these trip distance intervals, 20 city pairs were randomly selected. The city pair had to have air, rail and road (Bus) terminals. From the appropriate Schedule Guides, distances and trip times for each mode's city pair within each trip distance interval was recorded. Also the population** at each city was recorded. Then, the average velocity for each mode within a distance interval was calculated as follows:

T_{ijm} = Scheduled trip time between city i and city j for mode m.

D_{ijm} = Trip distance between city i and city j.

$V_{ijm} = \frac{D_{ijm}}{T_{ijm}}$

P_i = Population at City i.

* Official Airline Guide, Quck Reference North American Edition, R. H. Donnelly Corp., January 15, 1970.

** Botting, W. H. & Galey B. T., A Classification of Urbanized Areas for Transportation Analysis, Highway Research Board # 194, Dec '67.

P_j = Population at City j.

$\overline{V}_{km}$ = Average Velocity for mode m within distance interval k.

$$\therefore \quad \overline{V}_{km} = \sum \frac{P_i P_j \cdot V_{ij}}{\sum P_i P_j}$$

In order to diminish the bias to the velocity parameter from statistical "out-liers" (sample points significantly outside the cluster of normal points), the velocity for each trip had to be weighted. Lacking any other weighting as a surrogate, the population product was used. It was assumed that city pairs with the higher populations in a distance interval would attract the greater number of trips. Consequently trips between them would reflect better the average velocity for a trip distance interval.

In the same way that the average velocity was calculated, average trip distances were calculated. The ratio between an air mile and any other mode mile within a distance interval was easily determined and the distance adjustment parameter (α_i) defined.

ACCESS - EGRESS TIME MATRIX

Trip Length 250 Miles

MODE FOR MAJOR TRIP ELEMENT	ORIGIN INTERFACE ACCESS MODE	ORIGIN INTERFACE ACCESS WAITING (MIN)	ORIGIN INTERFACE TRAVEL TIME (MIN)	DESTINATION INTERFACE EGRESS MODE	DESTINATION INTERFACE EGRESS WAITING TIME (MIN)	DESTINATION EGRESS TRAVEL TIME (MIN)
AUTO	WALKING	0	3	WALKING	0	3
BUS	KISS & RIDE AUTO	18	21	KISS & RIDE AUTO	6	21
RAIL	KISS & RIDE AUTO	30	21	50% KISS & RIDE 50% TAXI	12	21
AIR	KISS & RIDE AUTO	36*	30	50% KISS & RIDE 50% TAXI	12	33

NEW MODES**

* Waiting Time includes 30 minutes for preflight reporting; 6 minutes walking from auto to ticket counter.

** Access or egress times become a function of the terminal location. Times for new modes are the same as those for the mode they are competing with unless the system was especially assigned with multi stations and ease of accessibility. Then assumptions according to DOT Study reports were used. (i.e., MAC or NEW TYPE Systems)

IDENTIFICATION LIST OF SYSTEMS

CODE # (MIC)	SYSTEM	CODE # (MIC)	SYSTEM
1	Auto	25	MAC-1
2	Lite Aircraft or Light Aircraft	26	NET 1-2
3	HSR-A	27	MAC-2
4	3rd. Level Aircraft	28	NET-3
5	Bus	29	Auto-Pallet or Auto-Palet
6	Train		
7	VTOL or Vertical Takeoff and Landing	30	HSR-C
8	STOL or Short Takeoff and Landing		
9	CTOL or Conventional Takeoff & Landing		
10	Subsonic Jet		
11	Supersonic Jet		
12	Light VTOL or Lite VTOL		
13	Helicopter		
14	TACV or Tracked Air Cushion Vehicle		
15	Business Helicopter		
16	Business Turboprop		
17	Business Jet		
18	Train (New)		
19	TVS or Tubular Vehicles Systems		
20	FTL-1 or Fast Transit Link		
21	FTL-2		
22	PAS or Public Auto Service		
23	TAXI		
24	Dial-A-Bus or DAB		

Input: Identifies Chart Run

Distance Interval: Identifies Major Trip Element Distance

CODE/

MIC: CODE # assigned to identify each system in the computer program used over a major trip element distance.
MIF: CODE # assigned to identify the system used to interface with the system used on the major trip element distance.
N : # of Passengers - identifies size of the group.
NV : # of Passengers with same time value within group N.
BICD: Beginning Distance for the one way major trip element distance, measured in air miles.
FICD: Ending Distance for the one way major trip element distance, measured in air miles.
TIF: Total roundtrip interface time - measured in hours.
CIF: Total cost of any travel during interface portion of the trip - takes into account roundtrip interface costs.
TD : Time spent at Destination - measured in hours.
CDT: Fixed cost at Destination.
RR : Cost of lodging in dollars/day.
CC : Cost of comfort.
P_1 : Integer which is a multiplier to change value of the fixed cost portion (BASE) of a system usually set at 1 (No change).
P_2 : Integer which is a multiphier to change value of cost/per mile (CPM) of a system. Usually set at 1 (No change).
NP : Integer used to indicate # of points (pairs) used to define block speed of a system on the major trip element part of a trip.
BS : Block Speed of a system on the major trip element part of a trip.
C_1 : Adjustment factor to change Air Mile Distance to System Distance.
C_2 : Decimal Factor to account for fraction of additional time required for comfort, convenience of food stops.
C_5 : Meal cost. The model is set to charge 50¢ for every hour of total trip time. C_5 allows adjustment, up or down $(+C_5, -C_6)$.
BASE: Fixed cost to use a system.
CPM: Cost/Mile to use a system over major trip element distance.
C_3 : Integer - Accounts for Parking fees.
C_4 : Integer - Accounts for the roundtrip, number of travelers, and applicable taxes.

Additional parameters which are in the original NASA Model that permit more detail along a major trip element (e.g., acceleration; deceleration for train trips) were not used.

CHART AA

Distance Interval 0-2.5 Miles (High Density)

CODE/	(BASE YR. SYSTEMS) AUTO	BUS	TRAIN	TAXI	1975 BASE + NEW TV CURVE	1980 BASE + MAC-1	1990 BASE + MAC-1 + MAC-2	2000 1990 + NEW TV CURVE
MIC	1	5	18	23		25	27	
MIF	6	6	6	6		6	6	
N	1	1	1	1		1	1	
NV	1	1	1	1		1	1	
BICD	0	0	0	0		0	0	
FICD	2.5	2.5	2.5	2.5		2.5	2.5	
TIF	.3	.5	.4	.2		.03	.03	
CIF	0	0	0	0		0	0	
TD	3	3	3	3		3	3	
CDT	0	0	0	0		0	0	
RR	8	0	0	0		0	0	
CC	-	-	-	-		0	0	
P_1	1	1	1	1		1	1	
P_2	1	1	1	1		1	1	
NP	1	1	1	1		1	1	
BS	10	8	12.5	15		10.9	12.3	
C_1	1	1	1	1		1	1	
C_2	0	0	0	0		0	0	
C_5	-.5	-.5	-.5	-.5		-.5	-.5	
BASE	0	0	0	.50		0	0	
CPM	.055	.03	.07	.50		17.5	37.5	
C_3	0	0	0	0		0	0	
C_4	2	2	2	2		2	2	

INPUT CHART AB

Distance Interval 0-2.5 Miles (Non-Urban)

(BASE YR. SYSTEMS)

1975 - 2000
(No New Sytems - T.V. Curve Shifts)

CODE/	AUTO	BUS
MIC	1	5
MIF	6	6
N	1	1
NV	1	1
BICD	0	0
FICD	2.5	2.5
TIF	.02	.6
CIF	0	0
TD	3	3
CDT	0	0
RR	8.	0
CC	0	0
P_1	1	1
P_2	1	1
NP	1	1
BS	20	15
C_1	1	1
C_2	0	0
C_5	-.5	-.5
BASE	0	0
CPM	.042	.035
C_3	0	0
C_4	2	2

INPUT CHART AC

Distance Interval 0-2.5 Miles (Other Urban)

CODE/	AUTO	BUS	TAXI	1975 BASE + DAB	1980 1975 + PAS	1990 (1980)	2000 (1990)
	(BASE YR. SYSTEMS)						
MIC	1	5	23	24	22	New T.V.	New T.V.
MIF	6	6	6	6	6		
N	1	1	1	1	1		
NV	1	1	1	1	1		
BICD	0	0	0	0	0		
FICD	2.5	2.5	2.5	2.5	2.5		
TIF	.3	.5	.2	.35	.08		
CIF	0	0	0	0	0		
TD	3	3	3	3	3		
CDT	0	0	0	0	0		
RR	8.	0	0	0	0		
CC	0	0	0	0	0		
P_1	1	1	1	1	1		
P_2	1	1	1	1	1		
NP	1	1	1	1	1		
BS	20	15	25	18	18		
C_1	1	1	1	1	1		
C_2	0	0	0	0	0		
C_5	-.5	-.5	-.5	-.5	-.5		
BASE	0	0	.50	0	0		
CPM	.055	.03	.50	.25	.135		
C_3	0	0	0	0	0		
C_4	2	2	2	2	2		

INPUT CHART BB

Distance Interval 2.5-20 Miles (Urban)

(BASE YR. SYSTEMS)

CODE/	AUTO	BUS	TRAIN	TAXI	1975 BASE + DAB	1980 1975 + NET-1&2	1990 1980 + FTL-1 + NET-3		2000 1990 + NEW TV + FTL-2
MIC	1	5	18	23	24	26	20	2[illegible]	21
MIF	6	6	6	6	6	6	6	6	6
N	1	1	1	1	1	1	1	1	1
NV	1	1	1	1	1	1	1	1	1
BICD	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
FICD	20	20	20	20	20	20	20	20	20
TIF	.2	.6	.5	.1	.15	.4	.64	.2	.2
CIF	0	0	0	0	0	0	.84	.02	.07
TD	6	6	6	6	6	6	6	6	6
CDT	0	0	0	0	0	0	0	0	0
RR	8.	0	0	0	0	0	0	0	0
CC	0	0	0	0	0	0	0	0	0
P	1	1	1	1	1	1	1	1	1
P	1	1	1	1	1	1	1	1	1
NP	1	1	1	1	1	1	1	1	1
BS	17.2	16.	18.9	20	13	50	100	50	100
C	1	1	1	1	1	1	1	1	1
C	0	0	0	0	0	0	0	0	0
C	-.5	-.5	-.5	-.5	-.5	-.5	- 5	-.5	-.5
BASE	0	0	0	.50	0	0	0	0	0
CPM	.047	.03	.05	50	.25	.07	.08	.10	.15
C	0	0	0	0	0	0	0	0	0
C	2	2	2	2	2	2	2	2	2

INPUT CHART BC

Distance Interval 2.5-20 Miles (Non-Urban)

(BASE YR. SYSTEMS)

CODE/	AUTO	BUS	TRAIN	1975	1980	1990	2000
MIC	1	5	18	NEW	NEW	NEW	NEW
MIF	6	6	1	T.V.	T.V.	T.V.	T.V.
N	1	1	1	CURVE	CURVE	CURVE	CURVE
NV	1	1	1				
BICD	2.5	2.5	2.5				
FICD	20	20	20				
TIF	.2	.6	.6				
CIF	0	0	.36				
TD	6	6	6				
CDT	0	0	0				
RR	8.	0	0				
CC	0	0	0				
P_1	1	1	1				
P_2	1	1	1				
NP	1	1	1				
BS	30	25	35				
C_1	1	1	1				
C_2	0	0	0				
C_5	-.5	-.5	-.5				
BASE	0	0	0				
CPM	.034	.029	.048				
C_3	0	0	0				
C_4	2	2	2				

INPUT CHART CC

Distance Interval 20-50 Miles (Urban)

CODE/	(BASE YR. SYSTEMS) AUTO	BUS	TRAIN	1975 BASE + NEW TV	1980 BASE + NEW TV	1990 1980 + FTL-1	2000 1990 + NET-3 + FTL-2	
MIC	1	5	18			20	28	21
MIF	6	6	1			6	6	6
N	1	1	1			1	1	1
NV	1	1	1			1	1	1
BICD	20	20	20			20	20	20
FICD	50	50	50			50	50	50
TIF	.2	.6	.6			.64	.2	.2
CIF	0	0	.42			.84	.02	.02
TD	6	6	6			6	6	6
CDT	0	0	0			0	0	0
RR	0	0	0			0	0	0
CC	0	0	0			0	0	0
P_1	1	1	1			1	1	1
P_2	1	1	1			1	1	1
NP	1	1	1			1	1	1
BS	35	30	40			100	50	101
C_1	1	1	1			1	1	1
C_2	0	0	0			0	0	0
C_5	-.5	-.5	-.5			-.5	-.5	-.5
BASE	0	0	0			0	0	0
CPM	.046	.029	.067			.08	.10	.15
C_3	0	0	0			0	0	0
C_4	2	2	2			2	2	2

INPUT CHART CD

Distance Interval 20-50 Miles (Non-Urban)

	(BASE YR. SYSTEMS)			1975		1980			
CODE/	AUTO	BUS	TRAIN	BASE+HSR-A + HELIO		1975 + AUTO PALET+HSRC + HELIO + TACV			
MIC	1	5	18	3	13	29	30	13	14
MIF	6	1	1	1	1	1	1	1	1
N	1	1	1	1	1	1	1	1	1
NV	1	1	1	1	1	1	1	1	1
BICD	20	20	20	20	20	20	20	20	20
FICD	50	50	50	50	50	50	50	50	50
TIF	.1	.7	.8	.8	.6	.4	.8	.6	.8
CIF	0	.68	.80	.80	40	.53	.80	40	.80
TD	6	6	6	6	6	6	6	6	6
CDT	0	0	0	0	0	0	0	0	0
RR	0	0	0	0	0	0	0	0	0
CC	0	0	0	0	0	0	0	0	0
P_1	1	1	1	1	1	1	1	1	1
P_2	1	1	1	1	1	1	1	1	1
NP	1	1	1	1	1	1	1	1	1
BS	40	26	45	55	195	130	70	220	106
C_1	1.1	1.18	1.325	1.325	1	1.325	1.325	1	1.325
C_2	0	0	0	0	0	0	0	0	0
C_5	-.5	-.5	-.5	-.5	-.5	-.5	-.5	-.5	-.5
BASE	0	0	0	0	4.20	0	0	4.28	0
CPM	.033	.029	.067	.118	.16	.08	.126	.16	.134
C_3	0	0	0	0	0	0	0	0	0
C_4	2	2	2	2	2	2	2	2	2

INPUT CHART CD (Continued)

Distance Interval 20-50 Miles (Non-Urban)

CODE/	1990 1980 HELIO + TACV + LITE VTOL + TVS			2000 1990 + NEW TIME VALUE
MIC	14	12	19	
MIF	1	1	1	
N	1	1	1	
NV	1	1	1	
BICD	20	20	20	
FICD	50	50	50	
TIF	.8	.6	.0	
CIF	.80	.40	.40	
TD	6	6	6	
CDT	0	0	0	
RR	0	0	0	
CC	0	0	0	
P_1	1	1	1	
P_2	1	1	1	
NP	1	1	1	
BS	106	250	170	
C_1	1.325	1	1	
C_2	0	0	0	
C_5	-.5	-.5	-.5	
BASE	0	6.00	0	
CPM	.134	.18	.15	
C_3	0	0	0	
C_4	2	2	2	

INPUT CHART DD

Distance Interval 50-200 Miles (Non-Urban)

(BASE YR. SYSTEMS)

					1975 BASE + HSRA + AIR				
CODE/	AUTO	BUS	TRAIN	CTOL	HSR-A	HELIO	L/AC	3RD LEVEL AC	STOL
MIC	1	5	18	9	3	13	2	4	8
MIF	6	1	1		1	1	1	1	1
N	1	1	1	1	1	1	1	1	1
NV	1	1	1	1	1	1	1	1	1
BICD	50	50	50	50	50	50	50	50	50
FICD	200	200	200	200	200	200	200	200	200
TIF	.2	2.10	2.80	3.8	2.8	2.10	3.10	3.80	3.8
CIF	0	1.88	4.42	6.12	4.42	4.42	6.12	6.12	6.12
TD	8	8	8	8	8	8	8	3	8
CDT	0	0	0	0	0	0	0	0	0
RR	8.	0	0	0	0	8	8	8	8
CC	0	0	0	0	0	0	0	0	0
F_1	1	1	1	1	1	1	1	1	1
P_2	1	1	1	1	1	1	1	1	1
NP	1	1	1	1	1	1	1	1	1
BS	45	44.1	41	147.4	111	100	200	210	260
C_1	1.453	1.453	1.535	1	1.535	1	1	1	1
C_2	.2	.1	0	0	0	0	0	0	0
C_5	-.25	-.25	-.25	-.5	-.25	-.25	-.25	-.25	-.25
BASE	0	0	0	6.44	0	9.60	0	7.50	16.30
CPM	.027	.029	.05	.057	.118	.32	.83	.05	.07
C_3	0	0	0	0	0	0	0	0	0
C_4	2	2	2	2	2	2	2	2	2

INPUT CHART DD (Continued)

Distance Interval 50-200 Miles (Non-Urban)

2000

1990 + HSRA + HSRC + AUTO PALET + TACV

CODE/	TVS +	L/VTOL +	3RD LEVEL AC +	VTOL
MIC	19	12	4	7
MIF	1	1	1	1
N	1	1	1	1
NV	1	1	1	1
BICD	50	50	50	50
FICD	200	200	200	200
TIF	2.8	2.10	3.80	2.10
CIF	4.42	4.42	6.12	4.42
TD	8	8	8	8
CDT	0	0	0	0
RR	0	0	8	8
CC	0	0	0	C
P_1	1	1	1	1
P_2	1	1	1	1
NP	1	1	1	1
BS	350	350	225	645
C_1	1.535	1	1	1
C_2	0	0	0	0
C_5	-.25	-.25	-.25	-.5
BASE	0	0	5.00	8.00
CPM	.15	.54	.033	.04
C_3	0	0	0	0
C_4	2	2	2	2

INPUT CHART DD (Continued)

Distance Interval 50-200 Miles (Non-Urban)

CODE/	HSRC +	AUTO PALET +	HELIO +	1980 BASE + HSRA + L/AC +	3RD LEVEL AC +	STOL +	VTOL +	TACV
MIC	30	29	13	2	4	8	7	14
MIF	1	1	1	1	1	1	1	1
N	1	1	1	1	1	1	1	1
NV	1	1	1	1	1	1	1	1
BICD	50	50	50	50	50	50	50	50
FICD	200	200	200	200	200	200	200	200
TIF	2.8	1.4	2.10	3.10	3.80	3.80	2.10	2.8
CIF	4.42	.47	4.42	6.12	6.12	6.12	4.42	4.42
TD	8	8	8	8	8	8	8	8
CDT	0	0	0	0	0	0	0	0
RR	0	0	0	8	8	8	8	0
CC	0	0	0	0	0	0	0	0
P_1	1	1	1	1	1	1	1	1
P_2	1	1	1	1	1	1	1	1
NP	1	1	1	1	1	1	1	1
BS	158	130	190	220	210	325	455	258
C_1	1.535	1.535	1	1	1	1	1	1.535
C_2	0	0	0	0	0	0	0	0
C_5	-.25	-.25	-.25	-.25	-.25	-.25	-.5	-.25
BASE	0	0	6.40	0	6.50	11.66	32.62	0
CPM	.126	.168	.16	.83	.043	.05	.14	.134
C_3	0	0	0	0	0	0	0	0
C_4	2	2	2	2	2	2	2	2

INPUT CHART DD (Continued)

Distance Interval 50-200 Miles (Non-Urban)

CODE/	LIGHT AC +	L/VTOL +	1990 BASE + HSRA + HSRC + AUTO PALET + 3RD LEVEL AC +	VTOL +	TVS
MIC	2	12	4	7	19
MIF	1	1	1	1	1
N	1	1	1	1	1
NV	1	1	1	1	1
BICD	50	50	50	50	20
FICD	200	200	200	200	50
TIF	3.10	2.10	3.80	2.10	.6
CIF	6.12	4.42	6.12	4.42	40
TD	8	8	8	8	6
CDT	0	0	0	0	0
RR	8	0	0	0	0
CC	0	0	0	0	0
P_1	1	1	1	1	1
P_2	1	1	1	1	1
NP	1	1	1	1	1
BS	310	250	225	610	170
C_1	1	1	1	1	1
C_2	0	0	0	0	0
C_5	-.25	-.25	-.25	-.50	-.25
BASE	0	0	5.00	16.00	4
CPM	.85	.61	.033	.08	.15
C_3	0	0	0	0	0
C_4	2	2	2	2	2

INPUT CHART EE

Distance Interval 200-500 Miles (Non-Urban)

CODE/	AUTO	BUS	TRAIN	CTOL	1975 BASE-HELIO + DD 75-DD BASE + SUBSONIC	1980 BASE + DD 80-HELIO + SUBSONIC
	(BASE YR. SYSTEMS)					
MIC	1	5	18	9	10	10
MIF					1	1
N	SAME AS DD UNLESS SPECIFIED				1	1
NV					1	1
BICD	200	200	200	200	200	200
FICD	500	500	500	500	500	500
TIF					3.8	3.8
CIF					6.12	6.12
TD					8	8
CDT					0	0
RR					0	0
CC					0	0
P_1					1	1
P_2					1	1
NP					1	1
BS	50	43.5	46.6	231.3	2.87	287
C_1	1.147	1.147	1.23	1	1	1
C_2	.1	.1	0	0	0	0
C_5	-.25	-.25	-.25	-.5	-.5	-.5
BASE				6.44	6.44	6.44
CPM	.027	.028	.05	.057	.057	.057
C_3	0	0	0	0	0	0
C_4	2	2	2	2	2	2

INPUT CHART EE (Continued)

Distance Interval 200-500 Miles (Non-Urban)

CODE/	1990 BASE + SUBSONIC + DD 90 - DD BASE	2000 BASE + DD 100 - DD BASE
MIC		
MIF		
N		
NV		
BICD		
FICD		
TIF		
CIF		
TD		
CDT		
RR		
CC		
P_1		
P_2		
NP		
BS		
C_1		
C_2		
C_5		
BASE		
CPM		
C_3		
C_4		

INPUT CHART FF

Distance Interval 500-1000 Miles (Non-Urban)

(BASE YR. SYSTEMS)

CODE/	AUTO	BUS	TRAIN	CTOL	1975 BASE + EE 75 - EE BASE - L/AC - 3RD LEVEL - STOL + SUBSONIC
MIC	1	5	18	9	10
MIF	SAME AS EE UNLESS SPECIFIED OTHERWISE				1
N					1
NV					1
BICD	500	500	500	500	500
FICD	1000	1000	1000	1000	1000
TIF					3.8
CIF					6.12
TD	24	24	24	24	24
CDT					0
RR					0
CC					0
P1					1
P2					1
NP					1
BS	55	37.5	40.2	250	410
C1	1.06	1.060	1.205	1	1
C2	.1	.1	0	0	0
C5	-.25	-.25	-.25	-.5	-.50
BASE	0			6.44	6.44
CPM	.027	.0288	.05	.057	.057
C3	0	0	0	0	0
C4	2	2	2	2	2

INPUT CHART FF (Continued)

Distance Interval 500-1000 Miles (Non-Urban)

CODE/	1980 BASE + EE 80 - EE BASE - L/AC - 3RD LEVEL AC - STOL - VTOL + SUBSONIC
MIC	10
MIF	1
N	1
NV	1
BICD	500
FICD	1000
TIF	3.8
CIF	6.12
TD	24
CDT	0
RR	0
CC	0
P_1	1
P_2	1
NP	1
BS	410
C_1	1
C_2	0
C_5	-.50
BASE	6.44
CPM	.057
C_3	0
C_4	2

INPUT CHART FF (Continued)

Distance Interval 500-1000 Miles (Non-Urban)

CODE/	1990 BASE + EE 90 - EE BASE - L/AC - 3RD LEVEL AC - STOL - VTOL + SUBSONIC	2000 EE 2000 + 1990
MIC	10	
MIF	1	
N	1	
NV	1	
BICD	500	
FICD	1000	
TIF	3.8	
CIF	6.12	
TD	24	
CDT	0	
RR	0	
CC	0	
P_1	1	
P_2	1	
NP	1	
BS	475	
C_1	1	
C_2	0	
C_5	-.50	
BASE	6.44	
CPM	.057	
C_3	0	
C_4	2	

INPUT CHART GG (Continued)

Distance Interval 1000-3500 Miles

CODE/	2000 1990 AIR + HSRC - AUTO PALET + HYPERSONIC
MIC	
MIF	
N	
NV	
BICD	
FICD	
TIF	
CIF	
TD	
CDT	
RR	
CC	
P_1	
P_2	
NP	
BS	
C_1	
C_2	
C_5	
BASE	
CPM	
C_3	
C_4	

INPUT CHART GG

Distance Interval 1000-3500 Miles

	(BASE YR. SYSTEMS)				1975 BASE +	1980 BASE +			1990 BASE +	
CODE/	AUTO	BUS	TRAIN	CTOL	SUB	SUPER	HSRC -	AUTO PALET	SUB	SUPER + HSRC - AUTO PALET
MIC	1	5	18	9	10	11	30	29	10	11
MIF		SAME AS EE			1	1	1	1	1	1
N		UNLESS SPECIFIED OTHERWISE			1	1	1	1	1	1
NV					1	1	1	1	1	1
BICD	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
FICD	3500	3500	3500	3500	3500	3500	3500	3500	3500	3500
TIF					3.8	3.8	2.8	1.4	3.8	3.8
CIF					6.12	6.12	4.42	.47	6.12	6.12
TD	24	24	24	24	24	24	24	24	24	24
CDT					0	0	0	0	0	0
RR					0	0	0	0	0	0
CC					0	0	0	0	0	0
P_1					1	1	1	1	1	1
P_2					1	1	1	1	1	1
NP					1	1	1	1	1	1
BS	55	41	50.2	333.8	475	1170	158	130	500	1300
C_1	1.19	1.19	1.28	1	1	1	1.28	1.28	1	1
C_2	.1	.1	0	0	0	0	0	.1	0	0
C_5	-.25	-.25	-.25	0	-.50	-.50	-.25	-.25	-.25	-.25
BASE	0	0	0	6.44	6.44	6.44	0	0	6.44	6.44
CPM	.027	.0288	.05	.057	.057	.057	.126	.168	.057	.057
C_3	0	0	0	0	0	0	0	0	0	0
C_4	2	2	2	2	2	2	2	2	2	2

MODEL RELATIONS USED IN MODIFIED

NASA MODAL SPLIT MODEL

TG = TIC + TIF + TLO + TD

TG - total time gone
TIC - total intercity travel time
TIF - total interface travel time
TLO - time charged to lodging
TD - time spent at destination

$$TIC = [2 + C2(MIC)] * C1(MIC) * \frac{DIC}{BS}$$

C1(MIC) - difference between air and ground milage
C2(MIC) - fuel, comfort, convenience and food stops
DIC - one-way intercity distance in air miles
BS - block speed

COT = GIC + CIFT + COM + CLO + COC + CDT + (NV*TC*VH)

COT - total round trip cost for given distance
CIC - intercity fare or cost of operation
CIFT - total interface cost
COM - cost of meals
CLO - cost of lodging
COC - cost of comfort
CDT - fixed cost at destination
NV - number of travelers with time value
TC - travel time that has value
VH - value of travelers time

CIC = C4[b(MIC) + [C1(MIC)*DIC*CM(MIC)]]

C4 - accounts for the round trip, number of travelers, and applicable taxes
B(MIC) - fixed part of fare
C1(MIC) - difference between air and ground
DIC - one way intercity distance in air miles
CM(MIC) - per mile part of fare

$$CM(MIC) = \frac{1}{BS} \left(CVAR + \frac{CFIX}{U}\right)$$

U = DPYR/BS
DPYR = 2*DIC*TRPD*260.

DPYR - total miles/year
TRPD - number of trips/working day
U - annual utilization
CVAR - fixed hourly cost
CFIX - fixed yearly cost

If rented CIC = RPH*TIC

RPH = rental rate in dollars/hour

CIFT = CIF + C3*(1 + .05*TG)

CIF - input variable for interface cost
C3 - accounts for parking fees

COM = N*(TIC + TIF) * (.% + C5)
CLO = N*RR*TLO
COC = N*TIC*CC

N - total number of travelers
C5 - meal cost
RR - lodging cost in dollars/day
CC - comfort cost in dollars/day

NOTE: RR = 0 for all systems except those listed below.

CODE # (MIC)

1 ------- Auto
2 ------- Light Aircraft
4 ------- 3rd. Level Aircraft
7 ------- VTOL
8 ------- STOL
12 ------- Light VTOL
13 ------- Helicopter

For these seven modes, the lodging time, and lodging cost is calculated as shown:

K = (TIC/16)

Lodging Time in Hours, LT

LT = K · 32

Cost of Lodging, CLO

CLO = K · 2 · RR · N

BIBLIOGRAPHY

Bibliography

1. American Trucking Trends, American Trucking Associations, Inc., Wash., D. C., 1967.

2. Appel, F. C. "The Coming Revolution in Transportation", National Georgraphic, Sept., 1969, pp. 301-341.

3. Bock, F. C. ITT Research Institute, Factors Influencing Modal Trip Assignment, Highway Research Program Report #57, Wash., D. C., 1968.

4. Batting, W. H., Goley, G. T., A Classification of Urbanized Areas for Transportation Analysis, Highway Research Record Number 194, Highway Research Board, National Research Council, Wash., D. C. 1967.

5. Bright, J. R. ed. Technological Forecasting For Industry and Government - Methods and Application, "Analysis of the Future of the Delphi Method," Olaf Helmer pp. 116-134, Prentice Hall Inc. Engelwood Cliff, New Jersey, 1968.

6. BUS FACTS, 34th edition (1966); Supplement to Bus Facts - 34th edition (1966), National Association of Motor Bus Owners, Wash., D. C., Apr., 1968.

7. Characteristics of Internal Truck Freight, Tri-State Transportation Commission, Interim Technical Report No. 4042-3512, N. Y., June, 1966.

8. Chicago Area Transportation Study, Final Report, Volume II, Data Projections, Chicago Area Transportation Study, Chicago, Ill., July 1960.

9. Cost of Operating an Automobile, Federal Highway Administration, U. S. Dept. of Transportation, Jan., 1968.

10. Drake, H. M., Kenyon G. C. and Galloway T. L., Time Value Analysis of Civil Passenger Transportation Short Haul, 1967, 1975 (Working Paper), December 17, 1969, NASA OART, Mission Analysis Division, Moffett Field, California, 1969.

11. Economic Report of the President, Transmitted to the Congress, February, 1970, United States Government Printing Office, Wash., D. C., 1970.

12. Faucett, J. Associates, Selected Statistics on Distance Hauls of Freight According to Transport Mode, Office of Ass't. Sec. Policy and Int'l. Affairs, U. S. Dept. of Transportation, Wash., D. C., Nov., 1969.

13. Freight Commodity Statistics, Interstate Commerce Commission, Wash., D. C., Dec., 1966.

14. "Freight Tariff E-1099 - A Class Rates," Trunk line Central Railroads Tariff Bureau, Wash., D. C., Sept., 1963.

15. French, A., Highway Ton-Miles, Highway Research Board, Report #82, National Academy of Sciences, Jan., 1965.

16. Handbook of Airline Statistics, Civil Aeronautics Board, Wash., D. C., 1967.

17. Highway Statistics 1965, Bureau of Public Roads, Federal Highway Administration, U. S. Dept. of Transportation, Wash., D. C., Apr., 1967.

18. Meyer, J. R., Kain, J. F., Wohl, M., The Urban Transportation Problem, Harvard University Press, Cambridge, Mass., 1965.

19. Murphy, R. D., "Transportation Costs-Inland Waterways" (Working Paper) Office of Ass't Sec. Policy and Int'l. Affairs, U. S. Dept. of Transportation, Wash., D. C., Oct., 1969.

20. National Planning Association Center for Economic Projections, Special Study of Transportation Consumption Expenditures to 1990; Office of the Ass't Sec. Policy and Int'l. Affairs, U. S. Dept. of Transportation, Wash., D. C., 1969.

21. Official Airline Guide, Ruben H. Donnelly Inc., Oak Brook, Ill., Nov., 1969.

22. Official Air Freight Rate Tariff No. 2, Section 1 - Table A, Airline Tariff Publishers, Inc., Wash., D. C., 1967.

23. Official Bus Guide, Russell's Guides, Inc., Cedar Rapids, Iowa, May 1966.; Jan., 1970.

24. Official Guide of the Railways, National Railway Publication Company, N. Y., N. Y., Dec., 1969.; Dec., 1970.

25. Regional Profile, Who Rides Taxis, Volume 1, Number 11, Tri-State Transportation Commission, New York, N. Y., Feb., 1969.

26. Report No. 68-N-1, Economic Projection Series, National Planning Association Center for Economic Projections, Wash., D. C., Jan., 1969.

27. "Shifts in Petroleum Transportation", Association of Oil Pipe lines, Wash., D. C., Mar., 1969.

28. Shippers Motor Class Rate Guide, Southern Motor Carrier Conference Tariff 504, Rate Table A, pp. 1, Shippers Service Bureau, Wash., D.C., 1968.

29. Smith, W. Associates - Evaluation of Bus Transit Demand in Middle Sized Urban Areas, Bureau of Public Roads, Wash., D.C., 1966.

30. Smith, W. Associates, Patterns of Car Ownership, Trip Generation and Trip Sharing in Urbanized Areas, Bureau of Public Roads, U.S. Dept. of Transportation, Wash., D.C., June 1968.

31. Standard Highway Mileage Guide, Rand McNally, 1967.

32. Standard Transportation Commodity Code - Numerical, Association of American Railroads, January, 1968.

33. Stanford Research Institute, Future Urban Transportation Systems, Urban Mass Transportation Administration, U.S. Dept. of Transportation, Wash., D.C., March, 1968.

34. Transport Statistics - 1962, "Oil Pipe Lines", Interstate State Commerce Commission, Wash., D.C., Part 6, 1962.

35. Transport Technological Trends, First Edition, Transportation of America, Wash., D.C., January, 1969.

36. Waterborne Commerce of the United States - Water Carriage Ton Miles, Dept. of Army, Corps of Engineers, Wash., D.C., 1965, Part 5; Supplement 2 to Part 5, 1965.

37. 1963 Census of Transportation, Volume 1, Passenger Transportation Survey, Bureau of the Census, U.S. Dept. of Commerce, Wash., D.C., 1967.

38. 1968 Transit Fact Books 1968 Edition, American Transit Association, Wash., D.C., 1969.

39. 81st. Annual Report, Interstate Commerce Commission, Wash., D.C., June 1967.

*U. S. GOVERNMENT PRINTING OFFICE : 1973 O - 498-487